GREAT BOOKS OF THE WESTERN WORLD

ROBERT MAYNARD HUTCHINS, *EDITOR IN CHIEF*

45.

LAVOISIER

FOURIER

FARADAY

ELEMENTS OF CHEMISTRY

BY ANTOINE LAURENT LAVOISIER

ANALYTICAL THEORY OF HEAT

BY JEAN BAPTISTE JOSEPH FOURIER

EXPERIMENTAL RESEARCHES IN ELECTRICITY

BY MICHAEL FARADAY



WILLIAM BENTON, *Publisher*

ENCYCLOPÆDIA BRITANNICA, INC

CHICAGO · LONDON TORONTO GENEVA SYDNEY · TOKYO



THE UNIVERSITY OF CHICAGO

The Great Books
is published with the editorial advice of the faculties
of The University of Chicago

GENERAL CONTENTS

ELEMENTS OF CHEMISTRY

BIOGRAPHICAL NOTE

Antoine Lavoisier, 1743-1794

Lavoisier was born in Paris, August 26, 1743 His father was attorney to the Parliament of Paris His mother was the daughter of the secretary to the Vice-Admiral of France and heiress to a considerable fortune

After completing his elementary education Lavoisier was sent to the *College Mazarin* His early ambitions were literary rather than scientific, and in 1760 he won second prize in a rhetorical contest Although on leaving the college he went on to prepare for law, and received his Licentiate in 1764, he devoted himself to science, studying, with well-known teachers of the time, mathematics, astronomy, botany, mineralogy, geology, and chemistry He also began to conduct experiments and observations of his own One of the earliest was

[illegible]

social activity, he gave ill-health as an excuse and for several months lived in retirement on a diet of milk

His formal career as a scientist began in 1763 when he was invited by Guettard, his teacher

[illegible]

entries in the first group, Lavoisier alone was singled out from the second for special mention and a gold medal from the King The work with Guettard also yielded material which Lavoisier worked up in the form of *mémoires* to be presented to the Academy of Science In 1768, after he had presented four such papers, two on hydrometry and two on gypsum, he was elected a member of the Academy His youth excited comment, and, as a friend of the family

[illegible]

search, Lavoisier, shortly after his nomination to the Academy, bought an interest in the *Ferme*, an association of financiers who had the privilege of collecting the national taxes in return for a fixed annual sum paid in advance to the Government His friends at the Academy did not entirely approve of this association, but it did provide him with the money he sought, and it also made him acquainted with Farmer-General Paulze, whose daughter he married in 1771

Lavoisier entered further into public life when the Government took over the manufacture of gunpowder Upon his suggestion, Turgot, Minister of the Treasury, canceled the private production of gunpowder and established the *Régie des poudres*, a four-man administrative committee headed by Lavoisier With this appointment he was assigned a house at the Arsenal, where with his own funds he established a fully-equipped laboratory, which he made available to all scientists interested in his work As his scientific fame increased, the

[illegible]

assistants of others, among whom was the Dupont who later went to America and founded the munitions firm.

Although occupied with many practical concerns in connection with the *Ferme* and the *Régie des poudres*, Lavoisier reserved six hours

His wife, who was fourteen at the time of her marriage, became an active partner in his research. She assisted in the laboratory, learned English so as to translate the technical works of Priestley and Cavendish, and drew the illustrations for the *Traité élémentaire de Chimie* (1789). He also engaged in many works of philanthropic nature, starting a model farm to demonstrate the advantages of scientific agriculture and planning the establishment of savings banks, insurance societies, canals and workhouses for improving the conditions of the community.

When the Revolution occurred, Lavoisier had long been a national figure. He was Director of the Academy of Sciences, deputy to the States-General of 1789, and a prominent member of the club founded to promote the cause of constitutional monarchy. For some years after 1789 Lavoisier continued to work as secretary and treasurer of the commission to secure uniformity of weights and measures. In 1791 he was made a member of the commission on arts and professions; his report for this commission, *Réflexions sur l'instruction publique* (1793), presented a detailed scheme for public free education. But almost from the beginning of the Revolution, Lavoisier had been under suspicion because of his association with the *Ferme* and *Régie des poudres*, and from early 1791 he was subjected to vitriolic attack from Marat. In 1794 he and the other farmers-general were placed on trial by the Revolutionary Tribunal and condemned to death. Lavoisier and his father-in-law were guillotined May 8, 1794, at the Place de la Révolution and their bodies thrown into nameless graves in the cemetery of La Madeleine.

CONTENTS

PREFACE

WHEN I began the following work, my only object was to extend and explain more fully the memoir which I read at the public meeting of the Academy of Sciences in the month of April, 1787, on the necessity of reforming and completing the nomenclature of chemistry While engaged in this employment, I perceived better than I had ever done before, the justice of the following maxims of the Abbé de Condillac, in his *Logic*, and some other of his works

'We think only through the medium of words —Languages are true analytical methods —Algebra, which is adapted to its purpose in every species of expression, in the most simple, most exact, and best manner possible, is at the same time a language and an analytical method —The art of reasoning is nothing more than a language well arranged "

Thus, while I thought myself employed only in forming a nomenclature and while I proposed to myself nothing more than to improve the chemical language my work transformed itself by degrees, without my being able to prevent it, into a treatise upon the elements of chemistry

The impossibility of separating the nomenclature of a science from the science itself is owing to this, that every branch of physical science must consist of three things the series of facts which are the objects of the science, the ideas which represent these facts, and the words by which these ideas are expressed Like three impressions of the same seal, the word ought to produce the idea, and the idea to be a picture of the fact And, as ideas are preserved and communicated by means of words, it necessarily follows that we cannot improve the language of any science without at the same time improving the science itself, neither can we, on the other hand, improve a science without improving the language or nomenclature which belongs to it However certain the facts of any science may be and however just the ideas we may have formed of these facts, we can only communicate false impressions to others while we want words by which these may be properly expressed

To those who will consider it with attention, the first part of this treatise will afford frequent proofs of the truth of the above observations But as in the conduct of my work, I have been obliged to observe an order of arrangement essentially differing from what has been adopted in any other chemical work yet published, it is proper that I should explain the motives which have led me to do so

It is a maxim universally admitted in geometry, and indeed in every branch of knowledge, that, in the progress of investigation we should proceed from known facts to what is unknown In early infancy, our ideas spring from our wants, the sensation of want excites the idea of the object by which it is to be gratified In this manner, from a series of sensations, observations, and analyses, a successive train of ideas arises so linked together that an attentive observer may trace back to a certain point the order and connection of the whole sum of human knowledge

When we begin the study of any science, we are in a situation respecting that science similar to that of children, and the course by which we have to advance is precisely the same which nature follows in the formation of their ideas In a child, the idea is merely an effect produced by a sensation, and, in the same manner, in commencing the study of a physical science, we ought to form no idea but what is a necessary consequence and immediate effect of an experiment or observation Besides, he that enters upon the career of science is in a less ad- [illegible] he may commit respecting the salutary or hurtful qualities of the objects which surround him On every occasion his judgments are corrected

by experience want and pain are the necessary consequences arising from false judgment gratification and pleasure are produced by judging aright Under such masters, we cannot fail to become well informed and we soon learn to reason justly, when want and pain are the necessary consequences of a contrary conduct

In the study and practice of the sciences it is quite different the false judgments we form neither affect our existence nor our welfare, and we are not forced by any physical necessity to correct them Imagination, on the contrary, which is ever wandering beyond the bounds of truth, joined to self love and that self-confidence we are so apt to indulge, prompts us to draw conclusions which are not immediately derived from facts so that we become in some measure interested in deceiving ourselves Hence, it is by no means to be wondered that, in the science of physics in general, men have often made suppositions instead of forming conclusions These suppositions, handed down from one age to another, acquire additional weight from the authorities by which they are supported, till at last they are received, even by men of genius, as fundamental truths

The only method of preventing such errors from taking place, and of correcting them when formed, is to restrain and simplify our reasoning as much as possible This depends entirely upon ourselves, and the neglect of it is the only source of our mistakes We must trust to nothing but facts these are presented to us by nature and cannot deceive We ought, in every instance, to submit our reasoning to the test of experiment and never to search for truth but by the natural road of experiment and observation Thus mathematicians obtain the solution of a problem by the mere arrangement of data and by reducing their reasoning to such simple steps, to conclusions so very obvious, as never [illegible] vance but from what is known to what is unknown, never to form any conclusion which is not an immediate consequence necessarily flowing from observation and experiment, and always to arrange the facts, and the conclusions which are drawn from them, in such an order as shall render it most easy for beginners in the study of chemistry thoroughly to understand them Hence, I have been obliged to depart from the usual order of courses of lectures and of treatises upon chemistry, which always assume the first principles of the science as known, when the pupil or the reader should never be supposed to know them till they have been explained in subsequent lessons In almost every instance, these begin by treating of the elements of matter and by explaining the table of affinities, without considering that, in so doing, they must bring the principal phenomena of chemistry into view at the very outset they make use of terms which have not been defined and suppose the science to be understood by the very persons they are only beginning to teach It ought likewise to be considered that very little of chemistry can be learned in a first course, which is hardly sufficient to make the language of the science familiar to the ears or the apparatus familiar to the eyes It is almost impossible to become a chemist in less than three or four years of constant application

These inconveniences are occasioned not so much by the nature of the subject as by the method of teaching it and, to avoid them, I was chiefly induced to adopt a new arrangement of chemistry, which appeared to me more consonant to the order of nature I acknowledge, however, that in thus endeavouring to avoid difficulties of one kind I have found myself involved in others of a different species, some of which I have not been able to remove, but I am persuaded that such as remain do not arise from the nature of the order I have adopted, but are rather consequences of the imperfection under which chemistry still labours This science still has many chasms, which interrupt the series of facts and often render it extremely difficult to reconcile them [illegible] connected together its actual progress, however, is so rapid, and the facts, under the modern doctrine, have assumed so happy an arrangement that we have ground to hope, even in our own times, to see it approach near to the highest state of perfection of which it is susceptible

The rigorous law from which I have never deviated, of forming no conclusions which are not fully warranted by experiment, and of never supplying the absence of facts, has prevented me from comprehending in this work the branch of chemistry which treats of affinities, although it is perhaps the best calculated of any part of chemistry for being reduced into a completely systematic body MM Geoffroy, Gellert, Bergman, Scheele, de Morveau, Kirwan, and many others, have collected a number of particular facts upon this subject, which only wait for a proper arrangement, but the principal data are still wanting, or, at least, those we have are either not sufficiently defined or not sufficiently proved to become the foundation upon which to build so very important a branch of chemistry This science of affinities, or elective attractions, holds the same place with regard to the other branches of chemistry as the higher or transcendental geometry does with respect to the simpler and elementary part and I thought it improper to involve those simple and plain elements, which I flatter myself the greatest part of my readers will easily understand, in the obscurities and difficulties which still attend that other very useful and necessary branch of chemical science

Perhaps a sentiment of self-love may, without my perceiving it, have given additional force to these reflections Mr de Morveau is at present engaged in publishing the article *Affinity* in the *Methodical Encyclopædia* and I had more reasons than one to decline entering upon a work in which he is employed

It will, no doubt, be a matter of surprise, that in a treatise upon the elements of chemistry there should be no chapter on the constituent and elementary parts of matter, but I shall take occasion, in this place, to remark that the fondness for reducing all the bodies in nature to three or four elements proceeds from a prejudice which has descended to us from the Greek philosophers The notion of four elements, which, by the variety of their proportions, compose all the known substances in nature, is a mere hypothesis assumed long before the first principles of experimental philosophy or of chemistry had any existence In those days, without possessing facts, they framed systems, while we, who have collected facts, seem determined to reject them when they do not agree with our prejudices The authority of these fathers of human philosophy still carry great weight, and there is reason to fear that it will even bear hard upon generations yet to come

It is very remarkable that, notwithstanding the number of philosophical chemists who have supported the doctrine of the four elements, there is not one who has not been led by the evidence of facts to admit a greater number of elements into their theory The first chemists that wrote after the revival of letters considered sulphur and salt elementary substances entering into the composition of a great number of substances, hence, instead of four, they admitted the existence of six elements Beccher assumes the existence of three kinds of earth, from the combination of which, in different proportions, he supposed all the varieties of metallic substances to be produced Stahl gave a new modification to this system and succeeding chemists have taken the liberty to make or to imagine changes and additions of a similar nature All these chemists were carried along by the influence of the genius of the age in which they lived, which contented itself with assertions without proofs or, at least, often admitted as proofs the slightest degrees of probability, unsupported by that strictly rigorous analysis required by modern philosophy

All that can be said upon the number and nature of elements is, in my opinion, confined to discussions entirely of a metaphysical nature The subject only furnishes us with indefinite problems, which may be solved in a thousand different ways, not one of which, in all probability, is consistent with nature I shall therefore only add upon this subject that if by the term *elements* we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable we know nothing at all about them, but, if we apply the term *elements*, or *principles of bodies*, to express our idea of the last point which analysis is capable of reaching, we must admit, as elements, all the substances into which we are capable, by any means, to reduce bodies by decomposition. Not that we are entitled to affirm that these substances we consider as simple may not be com-

pounded of two or even of a greater number of principles; but, as these principles cannot be separated, or rather as we have not hitherto discovered the means of separating them, they act with regard to us as simple substances, and we ought never to suppose them compounded until experiment and observation has proved them to be so.

The foregoing reflections upon the progress of chemical ideas naturally apply to the words by which these ideas are to be expressed. Guided by the work which, in the year 1787, Messrs. de Morveau, Berthollet, de Fourcroy, and I composed upon the Nomenclature of Chemistry, I have endeavoured, as much as possible, to denominate simple bodies by simple terms, and I was naturally led to name these first. It will be recollected that we were obliged to retain that name of any substance by which it had been long known in the world, and that in two cases only we took the liberty of making alterations; first, in the case of those which were but newly discovered and had not yet obtained names, or at least which had been known but for a short time, and the names of which had not yet received the sanction of the public; and secondly, when the names which had been adopted, whether by the ancients or the moderns, appeared to us to express evidently false ideas, when they confounded the substances to which they were applied with others possessed of different or perhaps opposite qualities. We made no scruple, in this case, of substituting other names in their room, and the greatest number of these were borrowed from the Greek language. We endeavoured to frame them in such a manner as to express the most general and the most characteristic quality of the substances; and this was attended with the additional advantage both of assisting the memory of beginners, who find it difficult to remember a new word which has no meaning, and of accustoming them early to admit no word without connecting with it some determinate idea.

To those bodies which are formed by the union of several simple substances we gave new names, compounded in such a manner as the nature of the substances directed; but, as the number of double combinations is already very considerable, the only method by which we could avoid confusion was to divide them into classes. In the natural order of ideas, the name of the class or genus is that which expresses a quality common to a great number of individuals: The name of the species, on the contrary, expresses a quality peculiar to certain individuals only.

These distinctions are not, as some may imagine, merely metaphysical, but are established by Nature. A child, says the Abbé de Condillac, is taught to give the name tree to the first one which is pointed out to him. The next one he sees presents the same idea, and he gives it the same name. This he does likewise to a third and a fourth, till at last the word tree, which he first applied to an individual, comes to be employed by him as the name of a class or a genus, an abstract idea, which comprehends all trees in general. But, when he learns that all trees serve not the same purpose, that they do not all produce the same kind of fruit, he will soon learn to distinguish them by specific and particular names. This is the logic of all the sciences and is naturally applied to chemistry.

The acids, for example, are compounded of two substances, of the order of those which we consider as simple; the one constitutes acidity, and is common to all acids, and, from this substance, the name of the class or the genus ought to be taken; the other is peculiar to each acid, and distinguishes it from the rest, and from this substance is to be taken the name of the species. But, in the greatest number of acids, the two constituent elements, the acidifying principle and that which it acidifies, may exist in different proportions, constituting all the possible points of equilibrium or of saturation. This is the case in the sulphuric and the sulphurous acids; and these two states of the same acid we have marked by varying the termination of the specific name.

Metallic substances which have been exposed to the joint action of the air and of fire lose their metallic lustre, increase in weight, and assume an earthy appearance. In this state, like the acids, they are compounded of a principle which is common to all and one which is peculiar to each. In the same way, therefore, we have thought proper to class them under a generic name, derived from the common principle, for which purpose we adopted the term ox-

ide, and we distinguish them from each other by the particular name of the metal to which *each belongs*

Combustible substances, which in acids and metallic oxides are a specific and particular principle are capable of becoming, in their turn common principles of a great number of substances The sulphurous combinations have been long the only known ones in this kind Now, however, we know, from the experiments of Messrs Vandermonde, Monge, and Berthollet, that charcoal may be combined with iron, and perhaps with several other metals, and that, from this combination, according to the proportions, may be produced steel, plumbago, &c We know likewise, from the experiments of M Pelletier, that phosphorus may be combined with a great number of metallic substances These different combinations we have classed under generic names taken from the common substance, with a termination which marks this analogy, specifying them by another name taken from that substance which is proper to each

The nomenclature of bodies compounded of three simple substances was attended with still greater difficulty, not only on account of their number, but, particularly, because we cannot express the nature of their constituent principles without employing more compound names In the bodies which form this class, such as the neutral salts for instance, we had to consider, 1st, the acidifying principle, which is common to them all, 2nd, the acidifiable principle which *constitutes* their *peculiar acid*, *3rd*, *the saline*, earthy, or metallic basis, which determines the particular species of salt Here we derived the name of each class of salts from the name of the acidifiable principle common to all the individ uals of that class and distinguished each species by the name of the saline, earthy, or metallic basis, which is peculiar to it

A salt, though compounded of the same three principles, may, nevertheless, by the mere difference of their proportion, be in three different states The nomenclature we have adopted would have been defective had it not expressed these different states and this we attained chiefly by changes of termination uniformly applied to the same state of the different salts

In short, we have advanced so far that from the name alone may be instantly found what the combustible substance is which enters into any combination, whether that combustible [illegible]

er the saturation be exact, or whether the acid or the basis be in excess

It may be easily supposed that it was not possible to attain all these different objects with- [illegible]

we considered that the ear is soon habituated to new words, especially when they are connected with a general and rational system The names, besides, which were formerly employed, such as *powder of algaroth*, *salt of alembroth*, *pompholix*, *phagadenic water*, *turbith mineral*, *colcothar*, and many others, were neither less barbarous nor less uncommon It required a great deal of practice, and no small degree of mem- [illegible]

names of *oil of tartar per deliquium*, *oil of vitriol*, *butter of arsenic and of antimony*, *flowers of zinc*, &c were still more improper, because they suggested false ideas for, in the whole mineral kingdom, and particularly in the metallic class, there exist no such things as butters, oils, or flowers, and, in short, the substances to which they give these fallacious names are nothing less than rank poisons

When *we published our essay on the nomenclature* of chemistry, we were reproached for having changed the language which was spoken by our masters, which they distinguished by their authority and handed down to us But those who reproach us on this account have forgotten that it was Bergman and Macquer themselves who urged us to make this reformation In a letter which the learned Professor of Upp- [illegible]

thus learn sooner [illegible]

the opinion of those who have gone before me, that I have stated only my own opinion, without examining that of others By this I have been prevented from doing that justice to my associates, and more especially to foreign chemists, which I wished to render them But I beseech the reader to consider that, if I had filled an elementary work with a multitude of quotations, if I had allowed myself to enter into long dissertations on the history of the science and the works of those who have studied it, I must have lost sight of the true object I had in view and produced a work the reading of which must have been extremely tiresome to beginners It is not to the history of the science or of the human mind, that we are to attend in an elementary treatise our only aim ought to be ease and perspicuity and with the utmost care to keep everything out of view which might draw aside the attention of the student it is a road which we should be continually rendering more smooth, and from which we should endeavour to remove every obstacle which can occasion delay The sciences from their own nature, present a sufficient number of difficulties, though we add not those which are foreign to them But, besides this, chemists will easily perceive that, in the first part of my work, I make very little use of any experiments but those which were made by myself if at any time I have adopted, without acknowledgment, the experiments or the opinions of M Berthollet, M Fourcroy, M de la Place, M Monge, or, in general, of any of those whose principles are the same as my own, it is owing to this circumstance, that frequent intercourse, and the habit of communicating our ideas, our observations and our way of thinking to each other, has established between us a sort of community of opinions in which it is often difficult for every one to know his own

The remarks I have made on the order which [illegible]

[illegible] completely elementar[illegible]

the object of which was to point out the most simple processes for obtaining the different kinds of known acids This part contains nothing which I can call my own and presents only a very short abridgment of the results of these processes, extracted from the works of different authors

In the third part, I have given a description, in detail, of all the operations connected with modern chemistry I have long thought that a work of this kind was much wanted, and I am convinced it will not be without use The method of performing experiments, and particularly those of modern chemistry, is not so generally known as it ought to be and had I, in the different *Mémoires* which I have presented to the Academy, been more particular in the detail of the manipulations of my experiments, it is probable I should have made myself better understood, and the science might have made a more rapid progress The order of the different matters contained in this third part appeared to me to be almost arbitrary and the only one I have observed was to class together, in each of the chapters of which it is composed, those operations which are most connected with one another I need hardly mention that this part could not be borrowed from any other work, and that, in the principal articles it contains, I could not derive assistance from anything but the experiments which I have made myself

I shall conclude this preface by transcribing literally, some observations of the Abbé de Condillac which I think describe, with a good deal of truth, the state of chemistry at a period not far distant from our own These observations were made on a different subject, but they will not, on this account, have less force, if the application of them be thought just

"Instead of applying observation to the things we wished to know, we have chosen rather to imagine them Advancing from one ill-founded supposition to another, we have at last bewildered ourselves amidst a multitude of errors These errors becoming prejudices, are, of course, adopted as principles, and we thus bewilder ourselves more and more The method, too, by which we conduct our reasonings is as absurd, we abuse words which we do not understand, and call this the art of reasoning

When matters have been brought this length, when errors have been thus accumulated, there is but one remedy by which order can be restored to the faculty of thinking this is to forget all that we have learned, to trace back our ideas to their source, to follow the train in which they rise, and, as Bacon says, to frame the human understanding anew

' This remedy becomes the more difficult in proportion as we think ourselves more learned Might it not be thought that works which treated of the sciences with the utmost perspicuity, with great precision and order, must be understood by everybody? The fact is, those who have never studied anything will understand them better than those who have studied a great deal, and especially than those who have written a great deal "

At the end of the fifth chapter, the Abbé de Condillac adds "But, after all, the sciences have made progress, because philosophers have applied themselves with more attention to observe and have communicated to their language that precision and accuracy which they have employed in their observations In correcting their language they reason better "

FIRST PART

OF THE FORMATION AND DECOMPOSITION OF AERIFORM FLUIDS—OF THE COMBUSTION OF SIMPLE BODIES, AND THE FORMATION OF ACIDS

CHAPTER I

Of the Combinations of Caloric, and the Formation of Elastic Aeriform Fluids or gases

THAT every body, whether solid or fluid is augmented in all its dimensions by any increase of its sensible heat was long ago fully established as a physical axiom or universal proposition, by the celebrated Boerhaave Such facts as [illegible]

[illegible]

a constant and general law of nature

When we have heated a solid body to a certain degree and have thereby caused its particles to separate from each other, if we allow the body to cool, its particles again approach each other in the same proportion in which they were separated by the increased temperature, the body returns through the same degrees of expansion which it before extended through and if it be brought back to the same temperature from which we set out at the commencement of the experiment it recovers exactly the same dimensions which it formerly oc- [illegible]

[illegible]

each other in any state hitherto known which, tho' a very singular conclusion is yet impossible to be denied

It is supposed that, since the particles of bodies are thus continually impelled by heat to separate from each other, they would have no connection between themselves and of consequence, that there could be no solidity in nature unless they were held together by some other power which tends to unite them and so to speak, to chain them together, which power, whatever be its cause or manner of operation we name *attraction*

[illegible]

place them beyond the sphere of attraction they lose the adhesion they before had with each other, and the body ceases to be solid

[illegible]

gree of temperature its particles being no longer held together by reciprocal attraction, it becomes liquid and, when we raise its temperature above 80° (212°), its particles giving way to the repulsion caused by the heat assume the state of vapour or gas, and the water is changed into an aeriform fluid

The same may be affirmed of all bodies in nature they are either solid or liquid or in the state of elastic aeriform vapour, according to [illegible]

are exposed

It is difficult to comprehend these phenom- [illegible]

ena, without admitting them as the effects of a real and material substance, or very subtile fluid, which, insinuating itself between the particles of bodies, separates them from each

in a very satisfactory manner

This substance, whatever it is, being the cause of heat, or, in other words, the sensation which we call *warmth* being caused by the accumulation of this substance, we cannot, in strict language, distinguish it by the term *heat* because the same name would then very improperly express both cause and effect For this reason, in the *Memoir* which I published in 1777[1], I gave it the names of *igneous fluid* and *matter of heat* And, since that time, in the work[2] published by M de Morveau, M Berthollet, M de Fourcroy, and myself, upon the reformation of chemical nomenclature, we thought it necessary to banish all periphrastic expressions, which both lengthen physical language and render it more tedious and less distinct, and which even frequently does not convey sufficiently just ideas of the subject intended Wherefore, we have distinguished the cause of heat, or that exquisitely elastic fluid which produces it, by the term of *caloric* Besides that this expression fulfils our object in the system which we have adopted, it possesses this further advantage, that it accords with every species of opinion, since strictly speak-

ever that may be, which separates the particles of matter from each other, so that we are still at liberty to investigate its effects in an abstract and mathematical manner

In the present state of our knowledge, we are unable to determine whether light be a modification of caloric, or if caloric be, on the contrary, a modification of light This, however, is indisputable, that, in a system where only decided facts are admissible, and where we avoid, as far as possible, to suppose any

produce different effects We therefore distinguish light from caloric, though we do not therefore deny that these have certain qualities in common, and that, in certain circumstances, they combine with other bodies almost in the same manner, and produce, in part, the same effects

What I have already said may suffice to determine the idea affixed to the word *caloric*, but there remains a more difficult attempt, which is to give a just conception of the manner in which caloric acts upon other bodies Since this subtile matter penetrates through the pores of all known substances since there

the knowledge of its properties by effects which are fleeting and with difficulty ascertainable It is in these things which we neither see nor feel that it is especially necessary to guard against the extravagance of our imagination, which forever inclines to step beyond the bounds of truth and is with great difficulty restrained within the narrow line of facts

We have already seen that the same body becomes solid, or fluid, or aeriform, according to the quantity of caloric by which it is penetrated, or, to speak more strictly, according as the repulsive force exerted by the caloric is equal to, stronger, or weaker, than the attraction of the particles of the body it acts upon

But, if these two powers only existed, bodies would become liquid at an indivisible degree of the thermometer and would almost instantaneously pass from the solid state of aggregation to that of aeriform elasticity Thus water, for instance, at the very moment when it ceases to be ice, would begin to boil, and would

power The pressure of the atmosphere prevents this separation, and causes the water to remain in the liquid state till it be raised to 80° of temperature (212°) above zero of the French thermometer, the quantity of caloric which it receives in the lowest temperature being insufficient to overcome the pressure of the atmosphere

bodies in that state of existence in the very instant of melting, as the smallest additional caloric would instantly separate their particles and dissipate them through the surrounding

[1] Collections of the French Academy of Sciences for that year p 420
[2] *Chemical Nomenclature*

medium Besides, without this atmospheric pressure we should not even have any aeriform fluids, strictly speaking, because the moment the force of attraction is overcome by the repulsive power of the caloric the particles would separate themselves indefinitely, having nothing to give limits to their expansion, unless their own gravity might collect them together, so as to form an atmosphere

Simple reflection upon the most common experiments is sufficient to evince the truth of these positions They are more particularly proved by the following experiment, which I published in the *Recueil de l' Académie* for 1777, p 426

Having filled with sulphuric ether[1] a small *narrow glass vessel A (Plate VII, Fig 17)*, standing upon its stalk P, the vessel, which is from twelve to fifteen lines[2] diameter, is to be covered by a wet bladder, tied round its neck with several turns of strong thread, for greater security, fix a second bladder over the first The vessel should be filled in such a manner with the ether as not to leave the smallest portion of air between the liquor and the bladder It is now to be placed under the recipient BCD of an air-pump, of which the upper part B ought to be fitted with a leathern lid, through which passes a wire EF, having its point F very sharp, and in the same receiver there ought to be placed the barometer GH The whole being thus disposed, let the recipient be exhausted, and then, by pushing down the wire EF, we make a hole in the bladder Immediately the

duced will sustain the mercury in the barometer attached to the airpump, at eight or ten inches in winter, and from twenty to twenty-five in summer To render this experiment more

The only effect produced in this experiment is the taking away the weight of the atmosphere, which, in its ordinary state, presses on the surface of the ether, and the effects result-

for the pressure of the atmosphere, and that the passing of the ether from the liquid to the aeriform state is accompanied by a considerable lessening of heat, because, during the evaporation, a part of the caloric, which was before in a free state, or at least *in equilibrio* in the surrounding bodies, combines with the ether and causes it to assume the aeriform state

The same experiment succeeds with all evaporable fluids, such as alcohol, water, and even mercury with this difference, that the atmosphere formed in the receiver by alcohol only supports the attached barometer about one inch in winter, and about four or five inches in summer, that formed by water, in the same situation, raises the mercury only a few lines, and that by quicksilver but a few fractions of a line There is therefore less fluid evaporated from alcohol than from ether, less from water than from alcohol, and still less from mercury than from either, consequently there is less caloric employed, and less cold produced, which quadrates exactly with the results of these experiments

Another species of experiment proves very

has not been printed, we have shown that, when ether is subjected to a pressure equal to twenty eight inches of the barometer or about the medium pressure of the atmosphere, it boils at the temperature of about 32° (104°), or 33° (106 25°), of the thermometer M de Luc, who has made similar experiments with spirit of wine, finds it boils at 67° (182 75°)

[1] As I shall afterwards give a definition and ex-

[2] Line (from the French *ligne*) equals one-twelfth of an inch —EDITOR.

[3] *Vide Recueil de l' Académie*, 1780 p 335.

I filled a large vessel ABCD (Plate vii, *Fig 15*) with water at 35° (110 75°), or 36° (113°), I suppose the vessel transparent, that we may see what takes place in the experiment, and we can easily hold the hands in water at that temperature without inconvenience Into it I plunged some narrow necked bottles F, G, which were filled with the water, after which they were turned up, so as to rest on their mouths on the bottom of the vessel Having next put some ether into a very small matrass, with its neck *a b c* twice bent as in the Plate I plunged this matrass into the water so as to have its neck inserted into the mouth of one of the bottles F Immediately upon feeling the effects of the heat communicated to it by the water in the vessel ABCD it began to boil and the caloric, entering into combination with it, changed it into elastic aeriform fluid, with which I filled several bottles successively, F, G, &c

This is not the place to enter upon the examination of the nature and properties of this aeriform fluid, which is extremely inflammable but, confining myself to the object at present in view, without anticipating circumstances which I am not to suppose the reader to know, I shall only observe that the ether, from this experiment, is almost only capable of existing in the aeriform state in our world for if the weight of our atmosphere was only equal to between 20 and 24 inches of the barometer instead of 28 inches, we should never be able to obtain ether in the liquid state, at least in summer and the formation of ether would consequently be impossible upon mountains of a moderate degree of elevation as it would be converted into gas immediately upon being produced, unless we employed recipients of extraordinary strength, together with refrigeration and compression And, lastly, the temperature of the blood being nearly that at which ether passes from the liquid to the aeriform state, it must evaporate in the *primae viae*, and consequently it is very probable the medical properties of this fluid depend chiefly upon its mechanical effect

These experiments succeed better with nitrous ether, because it evaporates in a lower temperature than sulphuric ether It is more difficult to obtain alcohol in the aeriform state because, as it requires 67° (182 75°) to reduce it to vapour, the water of the bath must be almost boiling, and consequently it is impossible to plunge the hands into it at that temperature

It is evident that, if water were used in the foregoing experiment, it would be changed into gas when exposed to a temperature superior to that at which it boils Although thoroughly convinced of this, M de Laplace and myself judged it necessary to confirm it by the following direct experiment We filled a glass jar A (Plate vii *Fig 5*) with mercury, and placed it with its mouth downwards in a dish B, likewise filled with mercury, and having introduced about two gross of water into the jar, which rose to the top of the mercury at CD, we then plunged the whole apparatus into an iron boiler, EFGH, full of boiling sea-water of the temperature of 85° (223 25°), placed upon the furnace GHIK Immediately upon the water over the mercury attaining the temperature of 80° (212°), it began to boil, and, instead of only filling the small space ACD, it was converted into an aeriform fluid which filled the whole jar the mercury even descended below the surface of that in the dish B, and the jar must have been overturned if it had not been very thick and heavy and fixed to the dish by means of iron wire Immediately after withdrawing the apparatus from the boiler, the vapour in the jar began to condense, and the mercury rose to its former station, but it returned again to the aeriform state a few seconds after replacing the apparatus in the boiler

We have thus a certain number of substances, which are convertible into elastic aeriform fluids by degrees of temperature not much superior to that of our atmosphere We shall afterwards find that there are several others which undergo the same change in similar circumstances, such as muriatic or marine acid, ammonia or volatile alkali, carbonic acid or fixed air, sulphurous acid, &c All of these are permanently elastic in or about the mean temperature of the atmosphere and under its common pressure

All these facts, which could be easily multiplied if necessary, give me full right to assume, as a general principle, that almost every body in nature is susceptible of three several states of existence solid, liquid, and aeriform, and that these three states of existence depend upon the quantity of caloric combined with the body Henceforwards I shall express these elastic aeriform fluids by the generic term *gas* and in each species of gas I shall distinguish between the caloric, which in some measure serves the purpose of a solvent, and the substance, which in combination with the caloric, forms the base of the gas

ter IV of this work, when I have previously given an account of the phenomena attendant upon the heating and cooling of bodies, and when I have established precise ideas concerning the composition of our atmosphere

We have already shown, that the particles of every substance in nature exist in a certain state of equilibrium, between that attraction which tends to unite and keep the particles together and the effects of the caloric which tends to separate them Hence the caloric not only surrounds the particles of all bodies on every side but fills up every interval which the particles of bodies leave between each other We may form an idea of this by supposing a vessel filled with small spherical leaden bullets, into which a quantity of fine sand is poured, which, insinuating into the intervals between the bullets, will fill up every void The balls, in this comparison, are to the sand which surrounds them exactly in the same situation as the particles of bodies are with respect to the

tained at a small distance from each other by the caloric

If, instead of spherical balls we substitute solid bodies of a hexahedral, octahedral, or any other regular figure, the capacity of the intervals between them will be lessened and consequently will no longer contain the same quantity of sand The same thing takes place, with respect to natural bodies the intervals left between their particles are not of equal capacity but vary in consequence of the different figures and magnitude of their particles, and of the distance at which these particles are main

bodies for containing the matter of heat As comparisons with sensible objects are of great use

wetted and penetrated by it, with a few reflections

If we immerge equal pieces of different kinds of wood, suppose cubes of one foot each, into water, the fluid gradually insinuates itself into their pores and the pieces of wood are augmented both in weight and magnitude but each species of wood will imbibe a different

bibed by the pieces will depend upon the nature of the constituent particles of the wood and upon the greater or lesser affinity subsisting between them and water Very resinous wood, for instance, though it may be at the same time very porous, will admit but little water We may therefore say that the different kinds of wood possess different capacities for receiving water, we may even determine, by means of the augmentation of their weights, what quantity of water they have actually absorbed, but, as we are ignorant how much water they contained previous to immersion, we cannot determine the absolute quantity they contain after being taken out of the water

The same circumstances undoubtedly take place with bodies that are immersed in caloric, taking into consideration, however that water is an incompressible fluid, whereas caloric is, on the contrary, endowed with very great elasticity or, in other words, the particles of ca-

casion very considerable diversities in the results of experiments made upon these two substances

onimous, but possess each a strict and determinate meaning, as in the following definitions

Free caloric is that which is not combined in any manner with any other body But, as we live in a system to which caloric has a very strong adhesion, it follows that we are never able to obtain it in the state of absolute freedom

Combined caloric is that which is fixed in bodies by affinity or elective attraction so as to form part of the substance of the body, even part of its solidity

By the expression *specific caloric* of bodies we understand the respective quantities of caloric requisite for raising a number of bodies of the same weight to an equal degree of tempera-

ture This proportional quantity of caloric depends upon the distance between the constituent particles of bodies and their greater or lesser degrees of cohesion, and this distance, or rather the space or void resulting from it, is, as I have already observed, called the *capacity of bodies for containing caloric*

Heat, considered as a sensation or, in other words, sensible heat, is only the effect pro-

pressions only in consequence of motion and we might establish it as an axiom *that*, WITHOUT MOTION, THERE IS NO SENSATION This general principle applies very accurately to the sensations of heat and cold when we touch a

contrary happens, when we touch a warm body, the caloric then passing from the body into our hand produces the sensation of heat If the hand and the body touched be of the same temperature, or very nearly so, we receive no impression, either of heat or cold because there is no motion or passage of caloric and thus no sensation can take place without some correspondent motion to occasion it

When the thermometer rises, it shows that free caloric is entering into the surrounding bodies the thermometer, which is one of these, receives its share in proportion to its mass and to the capacity which it possesses for containing caloric The change therefore which takes place upon the thermometer only announces a change of place of the caloric in those bodies of which the thermometer forms one part it only indicates the portion of caloric received, without being a measure of the whole quantity disengaged, displaced, or absorbed

The most simple and most exact method for determining this latter point is that described by M de Laplace, in the *Recueil de l Académie* 1780, p 364, a summary explanation of which will be found towards the conclusion of

containing heat, but the ratio of the increase or diminution of capacity produced by deter

quantity of caloric requisite for converting solid substances into liquids and liquids into elastic aeriform fluids, and, *vice versa*, what quantity of caloric escapes from elastic vapours in

with sufficient accuracy, we may one day be able to determine the proportional quantity of caloric necessary for producing the several species of gases I shall hereafter, in a separate chapter, give an account of the principal results of such experiments as have been made upon this head

It remains before finishing this article, to say a few words relative to the cause of the elasticity of gases and of fluids in the state of vapour It is by no means difficult to perceive that this elasticity depends upon that of caloric which seems to be the most eminently elastic body in nature Nothing is more readily conceived than that one body should become elastic by entering into combination with another body possessed of that quality We must allow that this is only an explanation of elasticity, by an assumption of elasticity, and that we thus only remove the difficulty one step further, and that the nature of elasticity, and the reason for caloric being elastic, remains still unexplained Elasticity in the abstract is nothing more than that quality of the particles of bodies by which they recede from each other when forced together This tendency in the particles of caloric to separate, takes place even at considerable distances We shall be satisfied of this, when we consider that air is susceptible of undergoing great compression, which supposes that its particles were previously very distant from each other, for the power of approaching together certainly supposes a previous distance, at least equal to the degree of approach Consequently, those particles of the air, which are already considerably distant from each other, tend to separate still farther In fact, if we produce Boyle's vacuum in a large receiver, the very last portion of air which remains spreads itself uniformly through the whole capacity of the vessel, however

the particles make an effort to separate them selves on every side, and we are quite ignorant at what distance, or what degree of rarefaction, *this effort ceases to act*

Here, therefore, exists a true repulsion between the particles of elastic fluids at least, circumstances take *place exactly as if* such a repulsion actually existed and we have very good right to conclude that the particles of caloric mutually repel each other When we are once permitted to suppose this repelling force, the *rationale* of the formation of gases, or aeriform fluids becomes *perfectly simple*, tho' we must, at the same time, allow that it is extremely difficult to form an accurate conception of this repulsive force acting upon very minute particles placed at great distances from each other

It is, perhaps, more natural to suppose that the particles of caloric have a stronger mutual attraction than those of any other substance and that these latter particles are forced asunder in consequence of this superior attrac*tion between the particles of the caloric*, which forces them between the particles of other bodies that they may be able to reunite with each other We have somewhat analogous to this idea in the phenomena which occur when a dry sponge is dipped into water the sponge swells its particles separate from each other and all its intervals are filled up by the water It is evident that the sponge in the act of swelling has acquired a greater capacity for containing water than it had when dry But we cannot certainly maintain that the introduction of water between the particles of the sponge has endowed them with a repulsive power, which tends to separate them from each other, on the contrary, the whole phenomena are produced by means of *attractive powers* and these are, 1st, the gravity of the water, and the power which it exerts on every side in common with all other fluids 2nd, the force of attraction which takes place between the *particles of the water, causing them to unite* together, 3rd, the mutual attraction of the particles of the sponge with each other, and, *lastly*, the reciprocal attraction which exists between the particles of the sponge and those of the water *It is easy to understand* that the explanation of this fact depends upon properly ent attractive powers, which, in conformity with the imperfection of our knowledge, we endeavour to express by saying that caloric *communicates a power of repulsion to the particles* of bodies

CHAPTER II

General Views Relative to the Formation and Composition of our Atmosphere

THESE views which I have taken of the formation of elastic aeriform fluids or gases throw *great light upon the original formation of the* atmospheres of the planets and particularly that of our earth We readily conceive that it must necessarily consist of a mixture of the following substances 1st, of all bodies that are susceptible of evaporation, or more strictly speaking, which are capable of retaining the state of aeriform elasticity in the temperature of our atmosphere and under a pressure equal to that of a column of twenty-eight inches of quicksilver in the barometer and 2nd, of all *substances, whether liquid or solid, which are* capable of being dissolved by this mixture of different gases

The better to determine our ideas relating to this subject, which has not hitherto been sufficiently considered let us, for a moment, conceive what change would take place in the various substances which compose our earth, if its temperature were suddenly *altered If, for* instance, we were suddenly transported into the region of the planet Mercury, where probably the common temperature is much superior to that of boiling water, the water of the earth and all the other fluids which are susceptible of the gaseous state at a temperature near to

the new atmosphere These new species of airs or gases would mix with those already exist

tion itself, for as, in proportion to the increase

of elastic fluids, the pressure of the atmosphere would be augmented, as every degree of pressure tends, in some measure, to prevent evaporation, and as even the most evaporable fluids can resist the operation of a very high [illegible]

that the new atmosphere would at last arrive at such a degree of weight that the water which had not hitherto evaporated would cease to boil and, of consequence, would remain liquid,

[illegible]

tend these reflections greatly further, and examine what change might be produced in such situations upon stones, salts, and the greater part of the fusible substances which compose the mass of our earth These would be softened, fused and changed into fluids, &c but these speculations carry me from my object, to which I hasten to return

By a contrary supposition to the one we have been forming if the earth were suddenly transported into a very cold region, the water [illegible]

with foreign and heterogeneous substances, would become opaque stones of various colours In this case, the air, or at least some part of the aeriform fluids which now compose the mass of our atmosphere, would doubtless lose its elasticity for want of a sufficient temperature to retain it in that state it would return to the liquid state of existence, and new liquids would be formed of whose properties we cannot, at present, form the most distant idea

[illegible]

same matter, or three particular modifications which almost all substances are susceptible of assuming successively, and which solely depend upon the degree of temperature to which they are exposed or, in other words, upon the quantity of caloric with which they are penetrated 2nd that it is extremely probable that air is a fluid naturally existing in a state of vapour, or, as we may better express it, that our atmosphere is a compound of all the fluids which are susceptible of the vaporous or permanently elastic state, in the usual temperature and under the common pressure 3rd, that it is not impossible we may discover, in our atmosphere, certain substances naturally very compact, even metals themselves, as a metallic substance, for instance, only a little more volatile than mercury, might exist in that situation

Amongst the fluids with which we are acquainted, some, as water and alcohol, are susceptible of mixing with each other in all proportions, whereas others, on the contrary, as quicksilver, water, and oil, can only form a momentary union, and, after being mixed together, separate and arrange themselves according to their specific gravities The same thing ought to, or at least may, take place in the atmosphere It is possible, and even extremely probable, that, both at the first creation and every day, gases are formed, which are with difficulty miscible with atmospheric air and are continually separating from it If these gases be specifically lighter than the general atmospheric mass, they must, of course, gather in the higher regions and form strata that float upon the common air The phenomena which accompany igneous meteors induce me to believe that there exists in the upper parts of our atmosphere a stratum of inflammable fluid in contact with those strata of air which produce the phenomena of the aurora borealis and other fiery meteors —I mean hereafter to pursue this subject in a separate treatise

CHAPTER III

Analysis of Atmospheric Air, and its Division into Two Elastic Fluids the One Fit for Respiration the Other Incapable of Being Respired

From what has been premised, it follows that our atmosphere is composed of a mixture of every substance capable of retaining the gaseous or aeriform state in the common temperature, and under the usual pressure which it experiences These fluids constitute a mass, in some measure homogeneous extending from the surface of the earth to the greatest height hitherto attained, of which the density continually decreases in the inverse ratio of the superincumbent weight But as I have before observed, it is possible that this first stratum is surmounted by several others consisting of very different fluids

Our business, in this place, is to endeavour to determine, by experiments, the nature of the elastic fluids which compose the inferior

and that of synthesis When, for instance, by combining water with alcohol we form the species of liquor called, in commercial language, brandy or spirit of wine, we certainly have a right to conclude that brandy, or spirit of wine, is composed of alcohol combined with water We can produce the same result by the analytical method, and in general it ought to be considered as a principle in chemical science never to rest satisfied without both these species of proofs

We have this advantage in the analysis of atmospherical air, being able both to decompound it, and to form it anew in the most satisfactory manner I shall, however, at present confine myself to recount such experiments as

view

I took a matrass A (Plate II, *Fig 14*) of

extremity of its neck E might be inserted under a bell glass FG, placed in a trough of quicksilver RRSS, I introduced four ounces of pure mercury into the matrass and, by means of a siphon, exhausted the air in the receiver FG,

twelve days, so as to keep the quicksilver always almost at its boiling point Nothing re-

nute, which, gradually augmenting to a suffi-

mercury, which during the four or five following days, gradually increased in size and number, after which they ceased to increase in either respect At the end of twelve days, see-

at the commencement of the experiment was about 50 cubic inches At the end of the experiment the remaining air, reduced to the same medium pressure and temperature, was

ments of the same nature

The air which remained after the calcination of the mercury in this experiment, and which was reduced to ⅚ of its former bulk, was no longer fit either for respiration or for combustion, animals being introduced into it were

than atmospherical air, were collected in the bell-glass.

A part of this air being put into a glass tube of about an inch diameter showed the following properties a taper burned in it with a dazzling splendour and charcoal, instead of consuming quietly as it does in common air, burnt with a flame attended with a decrepitating noise, like phosphorus, and threw out such a brilliant light that the eyes could hardly endure it. This species of air was discovered almost at the same time by M Priestley, M Scheele, and myself M Priestley gave it the name of *dephlogisticated air*, M Scheele called it *empyreal air* At first I named it *highly respirable air*, to which has since been substituted the term of *vital air* We shall presently see what we ought to think of these denominations

In reflecting upon the circumstances of this experiment, we readily perceive that the mercury, during its calcination, absorbs the salubrious and respirable part of the air, or, to speak more strictly the base of this respirable part that the remaining air is a species of mephitis, incapable of supporting combustion or respiration and consequently that atmospheric air is composed of two elastic fluids of different and opposite qualities As a proof of this important truth if we recombine these two elastic fluids, which we have separately obtained in the above experiment, viz the 42 cubic inches of mephitis, with the 8 cubic inches of respirable air we reproduce an air precisely similar to that of the atmosphere and possessing nearly the same power of supporting combustion and respiration, and of contributing to the calcination of metals

Although this experiment furnishes us with a very simple means of obtaining the two principal elastic fluids which compose our atmosphere separate from each other yet it does not give us an exact idea of the proportion in which these two enter into its composition for the *attraction of mercury to the respirable part of* the air, or rather to its base, is not sufficiently strong to overcome all the circumstances which oppose this union These obstacles are the mutual adhesion of the two constituent parts of the atmosphere for each other and the elective attraction which unites the base of vital air with caloric in consequence of these, when the calcination ends, or is at least carried as far as is possible in a determinate quantity of atmospheric air, there still remains a portion of respirable air united to the mephitis, which the mercury cannot separate I shall afterwards show that, at least in our climate, the atmospheric air is composed of respirable, and mephitic airs, in the proportion of 27 and 73, and I shall then discuss the causes of the uncertainty which still exists with respect to the exactness of that proportion

Since, during the calcination of mercury, air is decomposed, and the base of its respirable part is fixed and combined with the mercury, it follows, from the principles already established, that caloric and light must be disengaged during the process but the two following causes prevent us from being sensible of this taking place as the calcination lasts during several days the disengagement of caloric and light, spread out in a considerable space of time, becomes extremely small for each particular moment of that time, so as not to be perceptible, and, in the next place, the operation being carried on by means of fire in a furnace, the heat produced by the calcination itself becomes confounded with that proceeding from the furnace I might add the respirable part of the air, or rather its base, in entering into combination with the mercury, does not part with all the caloric which it contained but still retains a part of it after forming the new compound, but the discussion of this point, and its proofs from experiment, do not belong to this part of our subject

It is, however, easy to render this disengagement of caloric and light evident to the senses, by causing the decomposition of air to take place in a more rapid manner And for this purpose, iron is excellently adapted, as it possesses a much stronger affinity for the base of respirable air than mercury The elegant experiment of M Ingenhouz, upon the combustion of iron, is well known Take a piece of fine iron wire twisted into a spiral BC (Plate IV, *Fig 17*), fix one of its extremities B into the cork A, adapted to the neck of the bottle DEFG, *and fix to the other extremity of the* wire C a small morsel of tinder Matters being thus prepared fill the bottle DEFG with air deprived of its mephitic part, then light the tinder and introduce it quickly, with the wire upon which it is fixed, into the bottle which you stop up with the cork A, as is shown in the figure (*17*, Plate IV) The instant the tinder comes into contact with the vital air it begins to burn with great intensity, and, communicating the inflammation to the iron wire, it too takes fire and burns rapidly, throwing out

brilliant sparks, which fall to the bottom of the vessel in rounded globules, which become black in cooling but retain a degree of metallic splendour The iron thus burnt is more brittle even than glass and is easily reduced into powder, and is still attractable by the magnet, though not so powerfully as it was before combustion As M Ingenhouz has neither examined the change produced on iron nor upon the air by this operation, I have repeated the experiment under different circumstances, in an apparatus adapted to answer my particular views, as follows

Having filled a bell glass A (Plate IV, *Fig 3*) of about six pints measure with pure air, or the highly respirable part of air, I transported this jar by *means of a very flat vessel, into a quick*silver bath in the basin BC, and I took care to render the surface of the mercury perfectly dry both within and without the jar with blotting paper I then provided a small capsule of chinaware D, very flat and open, in which I placed some small pieces of iron, turned spirally and arranged in such a way as seemed most favourable for the combustion being communicated to every part To the end of one of these pieces of iron was fixed a small morsel of tinder, to which was added about the sixteenth part of a grain of phosphorus, and, by raising the bell-glass a little, the china capsule, with its contents, were introduced into the pure air I know that, by this means, some common air must mix with the pure air in the glass, but this,

into the siphon, a small piece of paper is twisted round its extremity In sucking out the air, if the motion of the lungs only be used, we cannot make the mercury rise above an inch or an inch and a half, but, by properly using the muscles of the mouth, we can, without difficulty, cause it to rise six or seven inches

I next took an iron wire, (MN, Plate IV, *Fig 16*) properly bent for the purpose, and making it red hot in the fire passed it through the mercury into the receiver and brought it in contact with the small piece of phosphorus attached to the tinder The phosphorus instantly takes fire, which communicates to the tinder, and from that to the iron When the pieces have been properly arranged, the whole iron burns, even to the last particle, throwing out a white brilliant light similar to that of Chinese fireworks The great heat produced by this combustion melts the iron into round globules of different sizes, most of which fall into the china

glass, from the dilatation caused by the heat, but, presently afterwards, a rapid diminution of the air takes place and the mercury rises in the glass, insomuch that, when the quantity of iron is sufficient, and the air operated upon is very pure, almost the whole air employed is absorbed

It is proper to remark in this place that, unless in making experiments for the purpose of discovery, it is better to be contented with burning a moderate quantity of iron, for, when this experiment is pushed too far, so as to absorb much of the air, the cup D, which floats upon the quicksilver, approaches too near the bottom of the bell glass, and the great heat produced, which is followed by a very sudden

which happens the moment the least flaw is produced in the glass, causes such a wave as throws a great part of the quicksilver from the basin To avoid this inconvenience, and to ensure success to the experiment, one gross and a half of iron is sufficient to burn in a bell glass, which holds about eight pints of air The glass ought likewise to be strong, that it may be able to bear the weight of the column of mercury which it has to support

By this experiment, it is not possible to determine, at one time, both the additional weight acquired by the iron, and the changes which have taken place in the air If it is wished to ascertain what additional weight has been gained by the iron, and the proportion between that and the air absorbed, we must

fall to its level This being done, the bell glass is to be carefully removed, the globules of melted iron contained in the cup, and those which have been scattered about, and swim upon the mercury are to be accurately collected, and the whole is to be weighed The iron will be found in that state called *martial ethiops* by the old chemists, possessing a degree of metallic brilliancy, very friable, and readily reducible into powder under the hammer or with a pestle and mortar If the experiment has succeeded well, from 100 grains of iron will be obtained 135 or 136 grains of *ethiops*, which is an augmentation of 35 per cent

If all the attention has been paid to this experiment which it deserves, the air will be found diminished in weight exactly equal to what the iron has gained Having therefore burnt 100 grains of iron which has acquired an additional weight of 35 grains the diminution of air will be found exactly 70 cubic inches, and it will be found, in the sequel, that the weight of vital air is pretty nearly half a grain for each cubic inch so that, in effect, the augmentation of weight in the one exactly coincides with the loss of it in the other

I shall observe here, once for all, that, in every experiment of this kind the pressure and temperature of the air, both before and after the experiment, must be reduced by calculation, to a common standard of 10° (54 5°) of the thermometer and 28 inches of the barometer Towards the end of this work, the manner of performing this very necessary reduction will be found accurately detailed

If it be required to examine the nature of the air which remains after this experiment, we must operate in a somewhat different manner After the combustion is finished, and the vessels have cooled, we first take out the cup and the burnt iron, by introducing the hand through the quicksilver under the bell glass, we next introduce some solution of potash, or caustic alkali, or of the sulphuret of potash, or such other substance as is judged proper for examining their action upon the residuum of air I shall, in the sequel, give an account of these methods of analysing air, when I have explained the nature of these different substances, which are only here in a manner accidentally mentioned After this examination, so much water must be let into the glass as will displace the quicksilver, and then, by means of a shallow dish placed below the bell glass it is to be removed into the common water pneumato-chemical apparatus, where the air remaining may be examined at large and with great facility

When very soft and very pure iron has been employed in this experiment, and, if the combustion has been performed in the purest respirable or vital air, free from all admixture of the noxious or mephitic part, the air which remains after the combustion will be found as pure as it was before, but it is difficult to find iron entirely free from a small portion of charry matter, which is chiefly abundant in steel It is likewise exceedingly difficult to procure the pure air perfectly free from some admixture of mephitis, with which it is almost always contaminated, but this species of noxious air does not in the smallest degree disturb the result of the experiment, as it is always found at the end exactly in the same proportion as at the beginning

I mentioned before that we have two ways of determining the constituent parts of atmospheric air, the method of analysis, and that by synthesis The calcination of mercury has furnished us with an example of each of these methods since after having robbed the respirable part of its base, by means of the mercury, we have restored it, so as to recompose an air precisely similar to that of the atmosphere But we can equally accomplish this synthetic composition of atmospheric air by borrowing the materials of which it is composed from different kingdoms of nature We shall see hereafter that when animal substances are dissolved in the nitric acid a great quantity of gas is disengaged, which extinguishes light and is unfit for animal respiration, being exactly similar to the noxious or mephitic part of atmospheric air And if we take 73 parts, by weight, of this elastic fluid, and mix it with 27 parts of highly respirable air, procured from calcined mercury, we will form an elastic fluid precisely similar to atmospheric air in all its properties

There are many other methods of separating the respirable from the noxious part of the atmospheric air, which cannot be taken notice of in this part without anticipating information which properly belongs to the subsequent chapters The experiments already adduced may suffice for an elementary treatise, and, in matters of this nature, the choice of our evidences is of far greater consequence than their number

I shall close this article by pointing out the property which atmospheric air, and all the known gases, possess of dissolving water, which

is of great consequence to be attended to in all experiments of this nature M Saussure found, by experiment, that a cubic foot of atmos-

This water, held in solution by gases, gives rise to particular phenomena in many experiments

experiments

CHAPTER IV

Nomenclature of the Several Constituent Parts of Atmospheric Air

HITHERTO I have been obliged to make use of circumlocution to express the nature of the several substances which constitute our atmosphere having provisionally used the terms of *respirable* and *noxious*, or *non respirable parts of the air* But the investigations I mean *to undertake require a more direct mode of* expression and having now endeavoured to give simple and distinct ideas of the different substances which enter into the composition of the atmosphere, I shall henceforth express these ideas by words equally simple

The temperature of our earth being very

The same, however, has not been found necessary with respect to water reduced to the state of vapour by an additional dose of caloric since those persons who do not make a particular study of objects of this kind are still ignorant that water, when in a temperature only

occurs with all fluids and all substances which do not evaporate in the common temperature and under the usual pressure of our atmosphere

For similar reasons, names have not been given to the liquid or concrete states of most of the aeriform fluids these were not known to arise from the combination of caloric with certain bases, and, as they had not been seen either in the liquid or solid states their existence, under these forms was even unknown to natural philosophers

We have not pretended to make any alteration upon such terms as are sanctified by ancient custom and therefore continue to use the words *water* and *ice* in their common acceptation We likewise retain the word *air* to express that collection of elastic fluids which composes our atmosphere but we have not thought it necessary to preserve the same respect for modern terms, adopted by latter philosophers having considered ourselves as at liberty to reject such as appeared liable to occasion erroneous ideas of the substances they are meant to express, and either to substitute new terms *or to employ the old ones after modifying them* in such a manner as to convey more determinate ideas New words have been drawn, chiefly from the Greek language, in such a manner as to make their etymology convey some idea of what was meant to be represented and these we have always endeavoured to make short and of such a nature as to be changeable into adjectives and verbs

Following these principles, we have, after M Macquer's example, retained the term *gas* employed by van Helmont, having arranged the numerous classes of elastic aeriform fluids under that name, excepting only atmospheric air *Gas*, therefore, in our nomenclature becomes a generic term expressing the fullest degree of saturation in any body with caloric being, in fact, a term expressive of a mode of

and, following the same principles, we have *muriatic acid gas ammoniacal gas* and so on of every substance susceptible of being combined with caloric in such a manner as to assume the gaseous or elastic aeriform state

We have already seen that the atmospheric air is composed of two gases, or aeriform fluids, one of which is capable, by respiration, of contributing to animal life, and in which metals are calcinable and combustible bodies may burn, the other, on the contrary, is endowed with directly opposite qualities, it cannot be breathed by animals, neither will it admit of the combustion of inflammable bodies, nor of the calcination of metals We have given to the base of the former, or respirable portion of the air, the name of *oxygen*, from ὀξυς, *acidum*, and γείνομαι, *gignor*, because, in reality, one of the most general properties of this base is to form acids by combining with many different substances The union of this base with caloric we term *oxygen gas*, which is the same with what was formerly called *pure* or *vital air* The weight of this gas, at the temperature of 10° (54 50°), and under a pressure equal to 28 inches of the barometer, is half a grain for each cubic inch, or an ounce and a half to each cubic foot

The chemical properties of the noxious portion of atmospheric air being hitherto but little known, we have been satisfied to derive the name of its base from its known quality of killing such animals as are forced to breathe it, giving it the name of *azote*, from the Greek privative particle α and ζωή *vita* hence the name of the noxious part of atmospheric air is *azotic gas*, the weight of which, in the same temperature and under the same pressure, is 1 *oz* 2 *gros*[1] and 48 *grs* to the cubic foot, or 0 4444 of a grain to the cubic inch We cannot deny that this name appears somewhat extraordinary but this must be the case with all new terms, which cannot be expected to become familiar until they have been some time in use. We long endeavoured to find a more proper designation without success, it was at first proposed to call it *alkaligen gas*, as, from the experiments of M Berthollet, it appears to enter into the composition of ammonia, or volatile alkali, but then, we have as yet no proof of its making one of the constituent elements of the other alkalies, beside, it is proved to compose a part of the nitric acid, which gives as good reason to have called it *nitrogen* For these reasons, finding it necessary to reject any name upon systematic principles, we have considered that we run no risk of mistake in adopting the terms of *azote* and *azotic gas*, which only express a matter of fact, or that property which it possesses, of depriving such animals as breathe it of their lives.

I should anticipate subjects more properly reserved for the subsequent chapters were I in this place to enter upon the nomenclature of the several species of gases it is sufficient, in this part of the work, to establish the principles upon which their denominations are founded The principal merit of the nomenclature we have adopted is that, when once the simple elementary substance is distinguished by an appropriate term, the names of all its compounds derive readily, and necessarily, from this first denomination

[1] *Gros* equals one-eighth of an ounce —EDITOR.

CHAPTER V

Of the Decomposition of Oxygen Gas by Sulphur, Phosphorus, and Charcoal, and of the Formation of Acids in General

In performing experiments, it is a necessary principle, which ought never to be deviated from, that they be simplified as much as possible, and that every circumstance capable of rendering their results complicated be carefully removed Wherefore, in the experiments which form the object of this chapter, we have never employed atmospheric air, which is not a simple substance It is true that the azotic gas, which forms a part of its mixture, appears to be merely passive during combustion and calcination, but, besides that it retards these operations very considerably, we are not certain but it may even alter their results in some circumstances, for which reason I have thought it necessary to remove even this possible cause of doubt, by only making use of pure oxygen gas in the following experiments which show the effects produced by combustion in that gas, and I shall advert to such differences as take place in the results of these, when the oxygen gas, or pure vital air, is mixed, in different proportions, with azotic gas

Having filled a bell-glass A (Plate IV, Fig 3), of between five and six pints measure, with oxygen gas, I removed it from the water trough, where it was filled, into the quicksilver bath by means of a shallow glass dish slipped underneath, and having dried the mercury I introduced 61¼ grains of Kunkel's phosphorus in two little china cups, like that represented at D (Fig 3), under the glass A, and that I might set fire to each of the portions of phosphorus separately, and to prevent the one from catching fire from the other, one of the dishes was covered with a piece of flat glass, I next

raised the quicksilver in the bell glass up to EF, by sucking out a sufficient portion of the gas by means of the siphon GHI After this, by means of the crooked iron wire (*Fig 16*), made red hot, I set fire to the two portions of phosphorus successively, first burning that portion which was not covered with the piece of glass The combustion was extremely rapid, attended with a very brilliant flame and considerable disengagement of light and heat In consequence of the great heat induced, the gas was at first much dilated, but soon after the mercury returned to its level and a considerable absorption of gas took place, at the same time, the whole inside of the glass became covered with white light flakes of concrete *phosphoric acid*

At the beginning of the experiment, the quantity of oxygen gas, reduced, as above directed, to a common standard, amounted to 162 cubic inches and, after the combustion was finished, only 23¼ cubic inches, likewise reduced to the standard, remained so that the quantity of oxygen gas absorbed during the combustion was 138¾ cubic inches, equal to 69 375 grains

A part of the phosphorus remained unconsumed in the bottom of the cups, which being washed on purpose to separate the acid weighed about 16¼ grains, so that about 45 grains of phosphorus had been burned but, as it is hardly possible to avoid an error of one or two grains, I leave the quantity so far qualified Hence, as nearly 45 grains of phosphorus had, in this experiment, united with 69 375 grains of oxygen, and as no gravitating matter could have escaped through the glass, we have a right to conclude that the weight of the substance resulting from the combustion in form of white flakes must equal that of the phosphorus and oxygen employed, which amounts to 114 375 grains And we shall presently find that these flakes consisted entirely of a solid or concrete acid When we reduce these weights to hundredth parts, it will be found that 100 parts of phosphorus require 154 parts of oxy-

vincing manner, that, at a certain degree of temperature, oxygen possesses a stronger elective attraction, or affinity, for phosphorus than for caloric, that, in consequence of this, the *phosphorus attracts the base of oxygen gas* from the caloric, which, being set free, spreads itself over the surrounding bodies But, though this experiment be so far perfectly conclusive, it is not sufficiently rigorous, as, in the apparatus described, it is impossible to ascertain the weight of the flakes of concrete acid which are formed, we can therefore only determine this by calculating the weights of oxygen and phosphorus employed, but as, in physics and in chemistry, it is not allowable to suppose what is capable of being ascertained by direct experiment, I thought it necessary to repeat this experiment as follows, upon a larger scale and by means of a different apparatus

emery, and pierced with two holes for the tubes *yyy*, *xxx* Before shutting the balloon with its stopper, I introduced the support BC, surmounted by the china cup D, containing 150 *grs* of phosphorus, the stopper was then fitted to the opening of the balloon, luted with fat lute, and covered with slips of linen spread with quicklime and white of eggs when the

xxx, and then introduced oxygen gas by means of the tube *yyy*, having a stop-cock adapted to it This kind of experiment is most readily and most exactly performed by means of the hydropneumatic machine described by M Meusnier and me in the *Recueil de l Académie* for *1782*, page 466, and explained in the latter part of this work, with several important additions and corrections since made to it by M Meusnier With this instrument we can readily ascertain, in the most exact manner, both the quantity of oxygen gas introduced into the balloon and the quantity consumed during the course of the experiment

When all things were properly disposed, I set fire to the phosphorus with a burning glass The combustion was extremely rapid, accompanied with a bright flame and much heat as the operation went on, large quantities of white

allowed the apparatus to cool completely, I

first ascertained the quantity of oxygen gas employed and weighed the balloon accurately, before it was opened I next washed, dried and weighed the small quantity of phosphorus remaining in the cup, on purpose to determine the whole quantity of phosphorus consumed in the experiment this residuum of the phosphorus was of a yellow ochre colour It is evident that by these several precautions I could easily determine, 1st the weight of the phosphorus consumed 2nd the weight of the flakes produced by the combustion, and 3rd the weight of the oxygen which had combined with the phosphorus This experiment gave very nearly the same results with the former, as it proved that the phosphorus during its combustion had absorbed a little more than one and a half its weight of oxygen, and I learned with more certainty that the weight of the new substance produced in the experiment exactly equalled the sum of the weights of the phosphorus consumed and oxygen absorbed which indeed was easily determinable *a priori* If the oxygen gas employed be pure, the residuum after combustion is as pure as the gas employed, this proves that nothing escapes from the phosphorus capable of altering the purity of the oxygen gas and that the only action of the phosphorous is to separate the oxygen from the caloric with which it was before united

I mentioned above, that when any combustible body is burnt in a hollow sphere of ice, or in an apparatus properly constructed upon that principle, the quantity of ice melted during the combustion is an exact measure of the quantity of caloric disengaged Upon this head, the *Mémoire* given by M de Laplace and me, 1780, p 355, may be consulted Having submitted the combustion of phosphorus to this trial, we found that one pound of phosphorus melted a little more than 100 pounds of ice during its combustion

The combustion of phosphorus succeeds equally well in atmospheric air as in oxygen gas, with this difference, that the combustion is vastly slower, being retarded by the large proportion of azotic gas mixed with the oxygen gas, and that only about one-fifth part of the air employed is absorbed, because as the oxygen gas only is absorbed the proportion of the azotic gas becomes so great toward the close of the experiment as to put an end to the combustion

I have already shown that phosphorus is changed by combustion into an extremely light, white, flaky matter, and its properties are entirely altered by this transformation from being insoluble in water, it becomes not only soluble, but so greedy of moisture as to attract the humidity of the air with astonishing rapidity, by this means it is converted into a liquid considerably more dense and of more specific gravity than water In the state of phosphorus before combustion, it had scarcely any sensible taste, by its union with oxygen it acquires an extremely sharp and sour taste in a word, from one of the class of combustible bodies it is changed into an incombustible substance and becomes one of those bodies called acids

This property of a combustible substance to be converted into an acid, by the addition of oxygen we shall presently find belongs to a great number of bodies wherefore, strict logic requires that we should adopt a common term for indicating all these operations which produce analogous results, this is the true way to simplify the study of science, as it would be quite impossible to bear all its specific details in the memory if they were not classically arranged For this reason we shall distinguish this conversion of phosphorus into an acid by its union with oxygen, and in general every combination of oxygen with a combustible substance, by the term of *oxygenation* from which I shall adopt the verb to *oxygenate*, and of consequence shall say, that in *oxygenating* phosphorus we convert it into an acid

Sulphur is likewise a combustible body or, in other words, it is a body which possesses the power of decomposing oxygen gas by attracting the oxygen from the caloric with which it was combined This can very easily be proved by means of experiments quite similar to those we have given with phosphorus but it is necessary to premise that in these operations with sulphur the same accuracy of result is not to be expected as with phosphorus because the acid which is formed by the combustion of sulphur is difficultly condensible, and because sulphur burns with more difficulty, and is soluble in the different gases But I can safely assert, from my own experiments, that sulphur in burning absorbs oxygen gas that the resulting acid is considerably heavier than the sulphur burnt, that its weight is equal to the sum of the weights of the sulphur which has been burnt and of the oxygen absorbed, and lastly, that this acid is weighty, incombustible, and miscible with water in all proportions the only uncertainty remaining upon this head is with

regard to the proportions of sulphur and of oxygen which enter into the composition of the acid

Charcoal, which, from all our present knowl-

common temperature, under the pressure of our atmosphere, it remains in the state of gas, and requires a large proportion of water to combine with or be dissolved in This acid has however, all the known properties of other acids, though in a weaker degree, and combines, like them, with all the bases which are susceptible of forming neutral salts

The combustion of charcoal in oxygen gas may be effected like that of phosphorus in the bell glass A (Plate IV, *Fig 3) placed over mercury* but, as the heat of red hot iron is not sufficient to set fire to the charcoal, we must add a small morsel of tinder with a minute particle of phosphorus in the same manner as directed in the experiment for the combustion of iron A detailed account of this experiment will be found in the *Recueil de l Académie* for 1781, p 448 By that experiment it appears that 28 parts by weight of charcoal require 72 parts of oxygen for saturation and that the aeriform acid produced is precisely equal in weight to the sum of the weights of the charcoal and oxygen gas employed This aeriform acid was called *fixed* or *fixable air* by the chemists who first discovered it, they did not then know whether it was air resembling that of the atmosphere or some other elastic fluid, vitiated and corrupted by combustion, but since it is now ascertained to be an acid, formed like all others by the oxygenation of its peculiar base, it is obvious that the name of *fixed air* is quite ineligible

inch, in the common standard temperature and pressure mentioned above, so that 34,242 cubic *inches* of acid gas are produced by the combustion of one pound of charcoal

I might multiply these experiments and show by a numerous succession of facts that all acids are formed by the combustion of certain sub-

tained to such as are unknown and of drawing my examples only from circumstances already explained In the mean time, however, the three examples above cited may suffice for giving a clear and accurate conception of the manner in which acids are formed By these it may be clearly seen that oxygen is an element common to them all which constitutes their acidity, and that they differ from each other according to the nature of the oxygenated or acidified substance We must therefore, in every acid, carefully distinguish between the acidifiable base, which M de Morveau calls the *radical*, and the acidifying principle or oxygen

CHAPTER VI

Of the Nomenclature of Acids in General, and Particularly of Those Drawn from Nitre and Sea Salt

It becomes extremely easy, from the principles laid down in the preceding chapter, to establish a systematic nomenclature for the acids the word *acid* being used as a generic term, each acid falls to be distinguished in language, as in nature, by the name of its base or radical Thus we give the generic name of acids to the products of the combustion or oxygenation of phosphorus, of sulphur, and of charcoal, and these products are respectively named the *phosphoric acid*, the *sulphuric acid*, and the *carbonic acid*

There is, however, a remarkable circumstance in the oxygenation of combustible

the union of the same elements, are possessed of different properties, depending upon that difference of proportion. Of this, the phosphoric acid and more especially the sulphuric, furnishes us with examples When sulphur is combined with a small proportion of oxygen, it forms in this first or lower degree of oxygenation, a volatile acid, having a penetrating odour and possessed of very particular qualities *By a larger proportion of oxygen, it is* changed into a fixed, heavy acid, without any odour, and which by combination with other bodies, gives products quite different from

first ascertained the quantity of oxygen gas employed and weighed the balloon accurately, before it was opened. I next washed dried and weighed the small quantity of phosphorus remaining in the cup on purpose to determine the whole quantity of phosphorus consumed in the experiment this residuum of the phosphorus was of a yellow ochre colour It is evident that by these several precautions I could easily determine 1st, the weight of the phosphorus consumed, 2nd the weight of the flakes produced by the combustion and, 3rd, the weight of the oxygen which had combined with the phosphorus. This experiment gave very nearly the same results with the former, as it [illegible]

[illegible] substance produced in the experiment exactly equalled the sum of the weights of the phosphorus consumed and oxygen absorbed which indeed was easily determinable *a priori*. If the oxygen gas employed be pure, the residuum after combustion is as pure as the gas employed, this proves that nothing escapes from the phosphorus capable of altering the purity of the oxygen gas and that the only action of the phosphorous is to separate the oxygen from the caloric with which it was before united

I mentioned above, that when any combustible body is burnt in a hollow sphere of ice, or in an apparatus properly constructed upon that principle, the quantity of ice melted during the combustion is an exact measure of the quantity of caloric disengaged. Upon this head, the *Memoire* given by M de Laplace and me, 1780, p. 355, may be consulted. Having submitted the combustion of phosphorus to this trial, we found that one pound of phosphorus melted a little more than 100 pounds of ice during its combustion.

The combustion of phosphorus succeeds equally well in atmospheric air as in oxygen gas, with this difference, that the combustion [illegible]

[illegible] oxygen gas only is absorbed the proportion of the azotic gas becomes so great toward the close of the experiment as to put an end to the combustion.

I have already shown that phosphorus is changed by combustion into an extremely light, white, flaky matter, and its properties are entirely altered by this transformation from [illegible]

[illegible] gravity than water In the state of phosphorus before combustion, it had scarcely any sensible taste, by its union with oxygen it acquires an extremely sharp and sour taste in a word, from one of the class of combustible bodies it is changed into an incombustible substance and becomes one of those bodies called acids

This property of a combustible substance to be converted into an acid, by the addition of oxygen, we shall presently find belongs to a great number of bodies wherefore, strict logic requires that we should adopt a common term for indicating all these operations which pro- [illegible]

[illegible] substance, by the term of *oxygenation*, from [illegible]

[illegible] power of decomposing oxygen gas by attracting the oxygen from the caloric with which it was combined This can very easily be proved by means of experiments quite similar to those we have given with phosphorus, but it is necessary to premise that in these operations with sulphur the same accuracy of result is not to be expected as with phosphorus because the acid which is formed by the combustion of sulphur is difficultly condensible, and because sulphur burns with more difficulty, and is soluble in the different gases But I can safely assert, from my own experiments, that sulphur in burning absorbs oxygen gas, that the resulting acid is considerably heavier than the sulphur burnt, that its weight is equal to the sum of the weights of the sulphur which has been burnt and of the oxygen absorbed and Lastly that this acid is weighty, incombustible, and miscible with water in all proportions the only uncertainty remaining upon this head is with

regard to the proportions of sulphur and of oxygen which enter into the composition of the acid

Charcoal, which, from all our present knowl-

common temperature, under the pressure of our atmosphere, it remains in the state of gas, and requires a large proportion of water to combine with or be dissolved in This acid has however, all the known properties of other acids, though in a weaker degree, and combines, like them, with all the bases which are susceptible of forming neutral salts

The combustion of charcoal in oxygen gas may be effected like that of phosphorus in the bell glass A (Plate IV, *Fig 3*) placed over mercury but, as the heat of red hot iron is not sufficient to set fire to the charcoal, we must add a small morsel of tinder with a minute particle of phosphorus, in the same manner as directed in the experiment for the combustion of iron A detailed account of this experiment will be

called *fixed* or *fixable air* by the chemists who first discovered it, they did not then know whether it was air resembling that of the atmosphere or some other elastic fluid, vitiated and corrupted by combustion, but since it is now ascertained to be an acid, formed like all others by the oxygenation of its peculiar base, it is obvious that the name of *fixed air* is quite ineligible

By burning charcoal in the apparatus mentioned, p 24, M de Laplace and I found that one *lb* of charcoal melted 96 *lbs* 6 *oz* of ice,

inches of acid gas are produced by the combustion of one pound of charcoal

I might multiply these experiments and show by a numerous succession of facts that all acids are formed by the combustion of certain substances, but I am prevented from doing so in this place by the plan which I have laid down of proceeding only from facts already ascertained to such as are unknown and of drawing my examples only from circumstances already explained In the mean time, however the three examples above cited may suffice for giving a clear and accurate conception of the manner in which acids are formed By these it may be clearly seen that oxygen is an element common to them all which constitutes their acidity, and that they differ from each other according to the nature of the oxygenated or acidified substance We must therefore, in every acid, carefully distinguish between the acidifiable base, which M de Morveau calls the *radical*, and the acidifying principle or oxygen

CHAPTER VI

Of the Nomenclature of Acids in General, and Particularly of Those Drawn from Nitre and Sea Salt

It becomes extremely easy, from the principles laid down in the preceding chapter, to establish a systematic nomenclature for the acids the word *acid* being used as a generic term, each acid falls to be distinguished in language, as in nature, by the name of its base or radical Thus, we give the generic name of acids to the products of the combustion or oxygenation of phosphorus, of sulphur, and of charcoal, and these products are respectively named the *phosphoric acid*, the *sulphuric acid*, and the *carbonic acid*

There is, however, a remarkable circumstance in the oxygenation of combustible

furnishes us with examples When sulphur is combined with a small proportion of oxygen, it forms, in this first or lower degree of oxygenation, a volatile acid, having a penetrating odour and possessed of very particular qualities By a larger proportion of oxygen, it is changed into a fixed, heavy acid, without any odour, and which, by combination with other bodies, gives products quite different from

those furnished by the former In this instance, the principles of our nomenclature seem to fail, and it seems difficult to derive such terms from the name of the acidifiable base as shall distinctly express these two degrees of saturation, or oxygenation, without circumlocution By *reflection, however, upon the subject, or* perhaps rather from the necessity of the case, we have thought it allowable to express these varieties in the oxygenation of the acids by simply varying the termination of their specific names The volatile acid produced from sulphur was anciently known to Stahl under the name of *sulphurous* acid We have preserved that term for this acid from sulphur under-saturated with oxygen, and distinguish the other, or completely saturated or oxygenated acid, by the name of *sulphuric* acid We

ous We shall adopt this difference of termination for all the acids which assume several degrees of saturation Hence we have a phosphorous and a phosphoric acid, an acetous and an acetic acid, and so on, for others in similar circumstances

This part of chemical science would have been extremely simple, and the nomenclature of the acids would not have been at all perplexed as it is now *in the old nomenclature, if* the base or radical of each acid had been known when the acid itself was discovered Thus for instance, phosphorus being a known substance before the discovery of its acid, this latter was rightly distinguished by a term drawn from the name of its acidifiable base But when, on the contrary, an acid happened to be discovered before its base, or rather when the acidifiable base from which it was formed remained unknown, names were adopted for the two, which have not the smallest connection, and thus, not only the memory became burdened with useless appellations, but even the minds

ists having procured this acid from the vitriol of iron gave it the name of the vitriolic acid from the name of the substance which produced it, and they were then ignorant that the acid procured from sulphur by combustion was exactly the same

The same thing happened with the aeriform acid formerly called *fixed air*, it not being *known that this acid was the result of combin-*

that of *sulphuric*, and the name of *fixed air* into that of *carbonic acid* but it is impossible *to follow this plan with the acids whose bases* are still unknown, with these we have been obliged to use a contrary plan and, instead of forming the name of the acid from that of its base have been forced to denominate the unknown base from the name of the known acid, as happens in the case of the acid which is procured from sea-salt

To disengage this acid from the alkaline base with which it is combined, we have only to pour sulphuric acid upon sea-salt, immediately a brisk effervescence takes place, white vapours arise, of a very penetrating odour, and, by only gently heating the mixture, all the acid is driven off As in the common tem-

most simple and most commodious apparatus consists of a small retort G (Plate v, *Fig 5*), into which the sea-salt is introduced, well dried, we then pour on some concentrated sulphuric acid, and immediately introduce the beak of the retort under little jars or bell glasses A (same Plate and *Fig*), previously filled with quicksilver In proportion as the

mous quantity of it, as is proved by introducing a very thin layer of water into the glass which contains the gas, for, in an instant, the whole acid gas disappears and combines with the water

This latter circumstance is taken advantage of in laboratories and manufactures on purpose to obtain the acid of sea-salt in a liquid form, and for this purpose the apparatus (Plate IV, *Fig 1*) is employed It consists, 1st, of a tabulated retort A, into which the sea-salt, and after

L, L, L, L, half filled with water, intended for absorbing the gas disengaged by the distillation This apparatus will be more amply described in the latter part of this work.

Although we have not yet been able, either to compose or to decompound this acid of sea-salt, we cannot have the smallest doubt that it, like all other acids, is composed by the union of oxygen with an acidifiable base We have therefore called this unknown substance the *muriatic base*, or *muriatic radical*, deriving this name, after the example of M Bergman and M de Morveau, from the Latin word *muria*, which was anciently used to signify sea-salt Thus, without being able exactly to determine the component parts of *muriatic acid*, we design by that term a volatile acid, which retains the form of gas in the common temperature and pressure of our atmosphere, which combines with great facility, and in great quantity, with water, and whose acidifiable base adheres so very intimately with oxygen that no method has hitherto been devised for separating them If ever this acidifiable base of the muriatic acid is discovered to be a known substance, though now unknown in that capacity, it will be requisite to change its present denomination for one analogous with that of its base

In common with sulphuric acid, and several other acids, the muriatic is capable of different degrees of oxygenation, but the excess of oxygen produces quite contrary effects upon it from what the same circumstance produces upon the acid of sulphur The lower degree of oxygenation converts sulphur into a volatile gaseous acid, which only mixes in small proportions with water, whilst a higher oxygenation forms an acid possessing much stronger

muriatic acid, the direct reverse takes place, an additional saturation with oxygen renders it more volatile, of a more penetrating odour, less miscible with water, and diminishes its acid properties We were at first inclined to have denominated these two degrees of saturation in the same manner as we had done with the acid of sulphur, calling the less oxygenated *muriatous acid*, and that which is more saturated with oxygen *muriatic acid* but, as this latter gives very particular results in its combinations, and as nothing analogous to it is yet known in chemistry, we have left the name of muriatic acid to the less saturated and given the latter the more compounded appellation of *oxygenated muriatic acid*

Although the base or radical of the acid which is extracted from nitre or saltpetre be better known, we have judged proper only to modify its name in the same manner with that of the muriatic acid It is drawn from nitre by the intervention of sulphuric acid, by a process similar to that described for extracting the muriatic acid, and by means of the same apparatus (Plate IV, *Fig 1*) In proportion as the acid passes over, it is in part condensed in the balloon or recipient and the rest is absorbed by the water contained in the bottles

tion, a large quantity of oxygen gas, mixed with a small proportion of azotic gas, is disengaged

This acid, like all others, is composed of oxygen, united to an acidifiable base, and is even the first acid in which the existence of oxygen was well ascertained Its two constituent elements are but weakly united and are easily separated by presenting any substance with

universally adopted in society, in manufactures, and in chemistry, and, on the other hand, azote having been discovered by M Berthollet to be the base of volatile alkali, or ammonia, as well as of this acid, we thought it improper to call it nitric radical We have therefore continued the term of azote to the base of that part of atmospheric air which is likewise the nitric and ammoniacal radical, and we have named the acid of nitre, in its lower and higher degrees of oxygenation, *nitrous acid* in the former and *nitric acid* in the latter state, thus preserving its former appellation properly modified

Several very respectable chemists have disapproved of this deference for the old terms and wished us to have persevered in perfecting a new chemical language, without paying any respect for ancient usage, so that, by thus steering a kind of middle course, we have exposed ourselves to the censures of one sect of chemists, and to the expostulations of the opposite party

The acid of nitre is susceptible of assuming a great number of separate states, depending upon its degree of oxygenation or upon the proportions in which azote and oxygen enter into its composition By a first or lowest degree of oxygenation it forms a particular species of gas, which we shall continue to name *nitrous gas*, this is composed nearly of two parts, by weight, of oxygen combined with one part of azote, and *in* this state it is not miscible with water In this gas, the azote is by no means saturated with oxygen, but, on the contrary, has still a very great affinity for that element and even attracts it from atmospheric air, immediately upon getting into contact with it This combination of nitrous gas with atmospheric air has even become one of the methods for determining the quantity of oxygen contained *in* air and consequently for ascertaining its degree of salubrity

This addition of oxygen converts the nitrous

azote is below three parts, by weight, of the former to one of the latter, the acid is red coloured and emits copious fumes In this state,

of azote, the acid is clear and colourless, more fixed in the fire than the nitrous acid, has less odour, and its constituent elements are more firmly united This species of acid, in conformity with our principles of nomenclature, is called *nitric acid*

Thus, nitric acid is the acid of nitre, sur-

gree of oxygenation, we have afterwards, in the course of this work, given the generical name of *oxide*

CHAPTER VII

Of the Decomposition of Oxygen Gas by Means of Metals and the Formation of Metallic Oxides

Oxygen has a stronger affinity with metals heated to a certain degree than with caloric, in consequence of which, all metallic bodies, excepting gold, silver, and platinum, have the property of decomposing oxygen gas, by attracting its base from the caloric with which it was combined We have already shown in what manner this decomposition takes place, by means of mercury and iron, having observed, that, in the case of the first, it must be considered as a kind of gradual combustion, whilst, in the latter, the combustion is extremely rapid and attended with a brilliant flame The use of the heat employed in these operations is to separate the particles of the metal from each other and to diminish their attraction of cohesion or aggregation or, which is the same thing, their mutual attraction for each other

into an earthy pulverulent matter In this state metals must not be considered as entirely saturated with oxygen, because their action upon this element is counterbalanced by the power of affinity between it and caloric During the

with the latter in consequence of the excess of the latter over the former, which is, in general,

very inconsiderable Wherefore, when metallic substances are oxygenated in atmospheric air or in oxygen gas, they are not converted into acids like sulphur, phosphorus, and charcoal, but are only changed into intermediate substances, which, though approaching to the nature of salts, have not acquired all the saline properties The old chemists have affixed the name of *calx* not only to metals in this state but to every body which has been long exposed to the action of fire without being melted They have converted this word *calx* into a generical term, under which they confound calcareous earth, which from a neutral salt, which it really was before calcination, has been changed by fire into an earthy alkali, by *losing* half of its weight, with metals which, by the same means, have joined themselves to a new substance, whose quantity often *exceeds* half their weight, and by which they have been changed almost into the nature of acids This mode of classifying substances of so very opposite natures under the same generic name would have been quite contrary to our principles of nomenclature, especially as, by retaining the above term for this state of metallic substances, we must have conveyed very false ideas of its nature We have, therefore, laid aside the expression *metallic calx* altogether and have substituted in its place the term *oxide*, from the Greek word ὀξύς

By this may be seen that the language we have adopted is both copious and expressive The first, or lowest, degree of oxygenation in bodies converts them into *oxides*, a second degree of additional oxygenation constitutes the class of acids, of which the specific names, drawn from their particular bases, terminate

without converting them into acids, causes them to approach to the nature of salts Thus, we give the name of *oxide of sulphur* to that soft substance into which sulphur is converted by incipient combustion, and we call the yellow matter left by phosphorus, after combustion, by the name of *oxide of phosphorus* In the same manner, nitrous gas, which is azote

language throws great light upon all the operations of art and nature

We have already observed that almost all the metallic oxides have peculiar and permanent colours These vary not only in the different species of metals, but even according to the various degrees of oxygenation in the same metal Hence we are under the necessity of adding two epithets to each oxide, one of which indicates the metal *oxidated*, while the other indicates the peculiar colour of the oxide Thus, we have the black oxide of iron, the red oxide of iron, and the yellow oxide of iron, which expressions respectively answer to the old unmeaning terms of martial ethiops, colcothar, and rust of iron, or ochre We have likewise the gray, yellow, and red oxides of lead which answer to the equally false or insignificant terms, ashes of lead, massicot, and minium.

These denominations sometimes become rather long especially when we mean to indicate whether the metal has been oxidated in the air, by detonation with nitre, or by means of acids but then they always convey just and accurate ideas of the corresponding object which we wish to express by their use All this will be rendered perfectly clear and distinct by means of the tables which are added to this work

CHAPTER VIII

Of the Radical Principle of Water and of its Decomposition by Charcoal and Iron

UNTIL very lately, water has always been

unable to decompose it, or, at least, since the decomposition which took place daily before their eyes was entirely unnoticed But we mean to prove that water is by no means a simple or elementary substance I shall not

shall only bring forwards the principal proofs of the decomposition and composition of water, and I may venture to say that these will be convincing to such as consider them impartially

First Experiment

Having fixed the glass tube EF (Plate VII, *Fig 11*) of from 8 to 12 lines diameter across a furnace, with a small inclination from E to F, lute the superior extremity E to the glass retort A, containing a determinate quantity of distilled water, and to the inferior extremity F the worm SS fixed into the neck of the doubly tubulated bottle H, which has the bent tube KK adapted to one of its openings, in such a manner as to convey such aeriform fluids or gases as may be disengaged, during the experiment into a proper apparatus for determining their quantity and nature

To render the success of this experiment certain it is necessary that the tube EF be made of well annealed and difficultly fusible glass, and that it be coated with a lute composed of clay mixed with powdered stone ware, besides

celain, would answer better than one of glass for this experiment, were it not difficult to procure one so entirely free from pores as to prevent the passage of air or of vapours

When things are thus arranged, a fire is lighted in the furnace EFCD, which is supported of such a strength as to keep the tube EF red hot but not to make it melt, and, at the same time, such a fire is kept up in the furnace VVXX as to keep the water in the retort A continually boiling

In proportion as the water in the retort A is evaporated it fills the tube EF, and drives out the air it contained by the tube KK, the aque-

through the tube EF, without having undergone the intermediate incandescence

Second Experiment

The apparatus being disposed, as in the former experiment, 28 *grs* of charcoal, broken into moderately small parts and which have previously been exposed for a long time to a red heat in close vessels, are introduced into the tube EF Everything else is managed as in the preceding experiment

The water contained in the retort A is distilled, as in the former experiment, and, being condensed in the worm, falls into the bottle H, but, at the same time, a considerable quantity

carbonic acid gas weighing 100 *grs* and 380 cubic inches of a very light gas weighing only 13 7 *grs*, which takes fire when in contact with air, by the approach of a lighted body, and, when the water which has passed over into the bottle H is carefully examined it is found to have lost 85 7 *grs* of its weight Thus, in this experiment, 85 7 *grs* of water, joined to 28 *grs* of charcoal, have combined in such a way as to form 100 *grs* of carbonic acid, and 13 7 *grs* of a particular gas capable of being burnt

I have already shown, that 100 *grs* of carbonic acid gas consists of 72 *grs* of oxygen combined with 28 *grs* of charcoal, hence the 28 *grs* of charcoal placed in the glass tube have acquired 72 *grs* of oxygen from the water, and it follows that 85 7 *grs* of water are composed

only have complicated and obscured its results in the minds of the reader For instance, the inflammable gas dissolves a very small part of

[1] *In the latter part of this work will be found a particular account of the processes necessary for separating the different kinds of gases and for determining their quantities* —AUTHOR

the charcoal, by which means its weight is somewhat augmented and that of the carbonic gas proportionally diminished Altho' the alteration produced by this circumstance is very inconsiderable, yet I have thought it necessary to determine its effects by rigid calculation, and to report, as above, the results of the experiment in its simplified state, as if this circumstance had not happened At any rate, should any doubts remain respecting the consequences I have drawn from this experiment, they will be fully dissipated by the following experiments, which I am going to adduce in support of my opinion

Third Experiment

The apparatus being disposed exactly as in the former experiment with this difference, that instead of the 28 *grs* of charcoal the tube EF is filled with 274 *grs* of soft iron in thin plates, rolled up spirally The tube is made red hot by means of its furnace, and the water in the retort A is kept constantly boiling till it be all evaporated, and has passed through the tube EF so as to be condensed in the bottle H

No carbonic acid gas is disengaged in this experiment, instead of which we obtain 416 cubic inches or 15 *grs* of inflammable gas, thirteen times lighter than atmospheric air By examining the water which has been distilled, it is found to have lost 100 *grs* and the 274 *grs* of iron confined in the tube are found to have

oxygen gas

In this experiment we have a true *oxidation* of iron, by means of water, exactly similar to that produced in air by the assistance of heat

ly follows that water is composed of oxygen *combined with the base of an inflammable gas*, in the respective proportions of 85 parts, by

must find an appropriate term None that we could think of seemed better adapted than the word *hydrogen*, which signifies the *generative principle of water*, from υδορ *aqua*, and γεινομαι *gignor*[1] We call the combination of this element with caloric *hydrogen gas* and the term hydrogen expresses the base of that gas, or the radical of water

This experiment furnishes us with a new

with some other body, it always subsists in the aeriform or gaseous state, in the usual temperature and pressure of our atmosphere In this state of gas it is about 1/13 of the weight of an equal bulk of atmospheric air, it is not ab-

As the property this gas possesses in common with all other combustible bodies is nothing more than the power of decomposing air and carrying off its oxygen from the caloric with which it was combined, it is easily understood that it cannot burn unless in contact with air or oxygen gas Hence, when we set fire to a bottle full of this gas, it burns gently, first at the neck of the bottle, and then in the inside of it, in proportion as the external air gets in This combustion is slow and successive and only takes place at the surface of contact between the two gases It is quite different when the two gases are mixed before they are set on fire if, for instance, after having introduced one part of oxygen gas into a narrow mouthed bottle, we fill it up with two parts of hydrogen gas and bring a lighted taper or other burning body to the mouth of the bottle the combustion of the two gases takes place instantaneously with a violent explosion This experiment

[1] This expression *hydrogen* has been very severely

rupture of the bottle, of which the fragments will be thrown about with great force

If all that has been related above, concerning the decomposition of water, be exactly conformable to truth,—if, as I have endeavoured to prove, that substance be really composed of hydrogen, as its proper constituent element,

happens may be judged of by the following experiment

Fourth Experiment

terminate The first tube, H*h*, is intended to be adapted to an air pump, by which the balloon is to be exhausted of its air The second ture *gg*, communicates, by its extremity MM, with a reservoir of oxygen gas, with which the balloon is to be filled The third tube *d*D*d* communicates, by its extremity *d*NN, with a reservoir of hydrogen gas The extremity *d* of this tube terminates in a capillary opening, through which the hydrogen gas contained in the reservoir is forced, with a moderate degree of quickness, by the pressure of one or two inches of water The fourth tube contains a metallic wire GL, having a knob at its extremity L, intended for giving an electrical spark from L to d′, on purpose to set fire to the hydrogen gas this wire is moveable in the tube, that we may be able to separate the knob L from the extremity *d* of the tube D*d* The three tubes *d*D*d* , *gg*, and H*h*, are all provided with stop cocks

That the hydrogen gas and oxygen gas may be as much as possible deprived of water, they are made to pass, in their way to the baloon A, through the tubes MM, NN, of about an inch diameter, and filled with salts, which, from their deliquescent nature, greedily attract the moisture of the air such are the acetite of potash, and the muriate or nitrate of lime[1] These salts must only be reduced to a coarse powder, lest they run into lumps, and prevent the gases from getting through their interstices

We must be provided beforehand with a sufficient quantity of oxygen gas, carefully purified from all admixture of carbonic acid by long contact with a solution of potash[2]

We must likewise have a double quantity of hydrogen gas, carefully purified in the same manner by long contact with a solution of potash in water The best way of obtaining this gas free from mixture is by decomposing water with very pure soft iron, as directed in Exp 3 of this chapter

Having adjusted everything properly, as above directed, the tube H*h* is adapted to an

is before mentioned, force a small stream of hydrogen gas through its tube D*d*′, which we immediately set on fire by an electric spark By means of the above described apparatus, we can continue the mutual combustion of

sumed I have in another place[3] given a description of the apparatus used in this experiment and have explained the manner of ascertaining the quantities of the gases consumed with the most scrupulous exactitude

In proportion to the advancement of the combustion, there is a deposition of water upon the inner surface of the balloon or matrass A the water gradually increases in quantity and, gathering into large drops, runs down to the bottom of the vessel. It is easy to ascertain the quantity of water collected, by weighing the balloon both before and after the experiment Thus we have a twofold verification of our experiment, by ascertaining both the quantities of the gases employed and of the water formed by their combustion these two quantities must be equal to each other By an operation of this kind, M Meusnier and I ascertained that it required 85 parts, by weight, of oxygen, united to 15 parts of hydrogen, to compose 100 parts of water This experiment, which has not hitherto been published, was made in presence of a numerous committee from the Royal Academy We exerted the most scrupulous attention to its accuracy and have reason to believe that the above propositions cannot vary a two hundredth part from absolute truth

From these experiments, both analytical and synthetic, we may now affirm that we have ascertained, with as much certainty as is pos-

[1] See the nature of these salts in the second part of this book —AUTHOR.

[2] The method of obtaining this pure alkali of potash will be given in the sequel —AUTHOR

[3] See the third part of this work.—AUTHOR.

sible in physical or chemical subjects, that water is not a simple elementary substance

as only to subsist under the form of gas in the common temperature and pressure of our atmosphere

This decomposition and recomposition of water is perpetually operating before our eyes, in the temperature of the atmosphere, by means of compound elective attraction We shall presently see that the phenomena attendant upon vinous fermentation, putrefaction, and even vegetation, are produced, at least in a certain degree, by decomposition of water It is very extraordinary that this fact should have hitherto been overlooked by natural philosophers and chemists indeed, it strongly proves that, in chemistry as in moral philosophy, it is extremely difficult to overcome prejudices imbibed in early education and to search for truth in any other road than the one we have been accustomed to follow

I shall finish this chapter by an experiment much less demonstrative than those already related, but which has appeared to make more impression than any other upon the minds of many people When 16 ounces of alcohol are burnt in an apparatus[1] properly adapted for collecting all the water disengaged during the combustion, we obtain from 17 to 18 ounces of water As no substance can furnish a product larger than its original bulk, it follows that

of the elements of water, and the atmospheric air contains oxygen, which is the other element necessary to the composition of water This experiment is a new proof that water is a compound substance

CHAPTER IX

Of the Quantities of Caloric Disengaged from Different Species of Combustion

We have already mentioned that, when any body is burnt in the center of a hollow sphere of ice and supplied with air at the temperature of zero (32°), the quantity of ice melted from the inside of the sphere becomes a measure of

[1] See an account of this apparatus in the third part of this work.—AUTHOR

the relative quantities of caloric disengaged M de Laplace and I gave a description of the apparatus employed for this kind of experiment in the *Recueil de l Académie* for 1780, p 355, and a description and plate of the same apparatus will be found in the third part of this work

one pound of charcoal melted 96 *lbs* 8 *oz*,
one pound of hydrogen gas melted 295 *lbs* 9 *oz* 3½ *gros*

As a concrete acid is formed by the combustion of phosphorus, it is probable that very little caloric remains in the acid and, consequently, that the above experiment gives us very nearly the whole quantity of caloric con-

tained nearly an equal quantity before combustion, the error must be very small, as it will only consist of the difference between what was contained in the phosphorus before, and in the phosphoric acid after combustion

I have already shown in Chapter V that one pound of phosphorus absorbs one pound eight ounces of oxygen during combustion and since, by the same operation, 100 *lbs* of ice are melted, it follows that the quantity of caloric contained in one pound of oxygen gas is capable of melting 66 *lbs* 10 *oz* 5 *gros* 24 *grs* of ice

One pound of charcoal during combustion melts only 96 *lbs* 8 *oz* of ice, whilst it absorbs 2 *lbs* 9 *oz* 1 *gros* 10 *grs* of oxygen By the experiment with phosphorus, this quantity of oxygen gas ought to disengage a quantity of caloric sufficient to melt 171 *lbs* 6 *oz* 5 *gros* of

by the combustion of one pound of charcoal, we find that the quantity of caloric necessary

combustion of hydrogen gas and the conse-

quent formation of water During the combustion of one pound of hydrogen gas 5 *lbs* 10 *oz*

according to the experiment with phosphorus

tion with hydrogen gas as much caloric as melts 295 *lbs* 2 *oz* 3½ *gros* wherefore there remains in the water at zero (32°) formed during this experiment as much caloric as would melt 82 *lbs* 9 *oz* 7½ *gros* of ice

Hence as 6 *lbs* 10 *oz* 5 *gros* 24 *grs* of water are formed from the combustion of one pound of hydrogen gas with 5 *lbs* 10 *oz* 5 *gros* 24 *grs* of oxygen it follows that in each pound of water at the temperature of zero (32°) there exists as much caloric as would melt 12 *lbs*

omit for want of data to calculate its quantity From this it appears that water even in the state of ice contains a considerable quantity of caloric and that oxygen in entering into that combination retains likewise a good proportion

From these experiments we may assume the following results as sufficiently established

Combustion of phosphorus

From the combustion of phosphorus as related in the forego ng experiments it appears that one pound of phosphorus requires 1 *lb* 8 *oz* of oxygen gas for its combustion and that 2 *lbs.* 8 *oz* of concrete phosphoric acid are produced

The quantity of caloric d sengaged by the combustion of one pound of phosphorus expressed by the number of pounds of ice melted during that operation is	100 00000
The quantity disengaged from each pound of *oxygen during the combust on* of phosphorus, expressed in the same manner is	66 66667
The quant ty disengaged during the formation of one pound of phosphoric ac d	40 00000
The quantity remaining in each pound of phosphoric acid	0 00000[1]

Combustion of charcoal

In the combustion of one pound of charcoal 2 *lbs* 9 *oz* 1 *gros* 10 *grs* of oxygen gas are absorbed and 3 *lbs* 9 *oz* 1 *gros* 10 *grs* of carbonic acid gas are formed

Caloric d sengaged during the combust on of one pound of charcoal	96 50000
Caloric disengaged during the combustion of charcoal from each pound of	37 52823
	?7 0?024
gen after the combustion	29 13844
Caloric necessary for supporting one pound of carbonic acid in the state of gas	20 97960

Combustion of hydrogen gas

In the combustion of one pound of hydrogen gas 5 *lbs* 10 *oz* 5 *gros* 24 *grs* of oxygen gas are absorbed and 6 *lbs* 10 *oz* 5 *gros* 24 *grs* of water are formed

Caloric from each *lb* of hydrogen gas	295 58950
Caloric from each *lb* of oxygen gas	52 16280
Caloric d sengaged during the formation of each pound of water	41 33840
Caloric retained by each *lb* of oxygen after combustion with hydrogen	14 50386
Caloric retained by each *lb* of water at the temperature of zero (32°)	12 32823

Formation of nitric acid

When we combine nitrous gas with oxygen gas so as to form nitric or nitrous acid a degree of heat is produced which is much less considerable than what is evolved during the other combinations of oxygen whence it follows that oxygen when it becomes fixed in nitric acid retains a great part of the heat which it possessed in the state of gas It is certainly possible to determine the quantity of caloric which is disengaged during the combination of these two gases and consequently to determine what quantity remains after the combination takes place The first of these quantities might be

operate upon a large quantity of the two gases in a very troublesome and complicated apparatus By this consideration M de Laplace and I have hitherto been prevented from mak

AUTHOR.

ing the attempt In the meantime, the place of such an experiment may be supplied by calculations, the results of which cannot be very far from truth

M de Laplace and I deflagrated a convenient quantity of nitre and charcoal in an ice apparatus and found that twelve pounds of ice were melted by the deflagration of one pound of nitre We shall see, in the sequel, that one pound of nitre is composed, as below, of

potash	7 *oz*	6 *gros*	51 84 *grs*	=	4515 84 *grs*
dry acid	8	1	21 16	=	4700 16

The above quantity of dry acid is composed of

oxygen	6 *oz*	3 *gros*	66 34 *grs*	=	3738 34 *grs*
azote	1	5	25 82	=	961 82

By this we find that during the above deflagration 2 *gros* 1½ *gr* of charcoal have suffered combustion, alongst with 3738 34 *grs* or 6 *oz* 3 *gros* 66 34 *grs* of oxygen Hence, since 12 *lbs* of ice were melted during the combustion, it follows that one pound of oxygen burnt in the same manner would have melted 29 58320 *lbs* of ice To which the quantity of

tained to be capable of melting 29 13844 *lbs* of ice, we have for the total quantity of caloric remaining in a pound of oxygen, when combined with nitrous gas in the nitric acid 58 72164, which is the number of pounds of ice the caloric remaining in the oxygen in that state is capable of melting

We have before seen that, in the state of oxygen gas, it contained at least 66 66667, wherefore it follows that, in combining with azote to form nitric acid, it only loses 7 94502 Further experiments upon this subject are necessary to ascertain how far the results of this calculation may agree with direct fact This enormous quantity of caloric retained by oxygen in its combination into nitric acid ex-

Combustion of Wax

Having examined several cases of simple combustion, I mean now to give a few examples of a more complex nature One pound of wax-taper being allowed to burn slowly in an ice apparatus melted 133 *lbs* 2 *oz* 5½ *gros* of ice

According to my experiments in the *Recueil de l'Académie* for 1784, p 606, one pound of wax-taper consists of 13 *oz* 1 *gros* 23 *grs* of charcoal and 2 *oz* 6 *gros* 49 *grs* of hydrogen

By the foregoing experiments, the above quantity of charcoal ought to melt	79 39390 *lbs* of ice
The hydrogen should melt	52 37605
Total	131 76995 *lbs*

Thus, we see the quantity of caloric disengaged from a burning taper is pretty exactly conformable to what was obtained by burning separately a quantity of charcoal and hydrogen equal to what enters into its composition These experiments with the taper were several times repeated, so that I have reason to believe them accurate

Combustion of Olive Oil

We included a burning lamp, containing a determinate quantity of olive oil, in the ordinary apparatus and, when the experiment was finished, we ascertained exactly the quantities of oil consumed and of ice melted, the result was that during the combustion of one pound of olive oil, 148 *lbs* 14 *oz* 1 *gros* of ice were melted By my experiments in the *Recueil de l Académie* for 1784, and of which the following chapter contains an abstract, it appears that one pound of olive oil consists of 12 *oz* 5 *gros* 5 *grs* of charcoal and 3 *oz* 2 *gros* 67 *grs* of hydrogen By the foregoing experiments, that quantity of charcoal should melt 76 18723 *lbs*

lbs which gives an excess of 10 54554 in the result of the experiment above the calculated result, from data furnished by former experiments

This difference, which is by no means very considerable, may arise from errors which are unavoidable in experiments of this nature, or it may be owing to the composition of oil not being as yet exactly ascertained It proves, however, that there is a great agreement between the results of our experiments, respecting the combination of caloric and those which

tained by oxygen, after combining with metals, so as to convert them into oxides, what quantity is contained by hydrogen, in its different states of existence, and to ascertain, with more precision than is as yet attained, how much caloric is disengaged during the formation of water, as there still remain considerable doubts with respect to our present determination of this point, which can only be removed by further experiments We are at present occupied with this inquiry and when once these several points are well ascertained which we hope they will soon be, we shall probably be under the necessity of making considerable corrections upon most of the results of the experiments and calculations in this chapter I did not, however, consider this as a sufficient reason for withholding so much as is already known from such as may be inclined to labour upon the same subject It is difficult in our endeavours to discover the principles of a new science, to avoid beginning by guess work, and it is rarely possible to arrive at perfection from the first setting out

CHAPTER X

Of the Combination of Combustible Substances with Each Other

As combustible substances in general have a great affinity for oxygen, they ought likewise to attract or tend to combine with each other, *quae sunt eadem uni tertio, sunt eadem inter se,* and the axiom is found to be true Almost all the metals, for instance, are capable of uniting with each other and forming what are called *alloys*[1] in common language Most of these, like all combinations, are susceptible of several degrees of saturation, the greater number of these alloys are more brittle than the pure metals of which they are composed, especially

nomena attendant upon *alloyage* are owing, particularly the property of iron called by workmen *hotshort* This kind of iron must be

mixture is malleable, but, if heated to a sufficient degree to liquefy the more fusible metal, the particles of the liquid metal, which are interposed between the particles of the metal remaining solid, must destroy their continuity and occasion the alloy to become brittle The alloys of mercury, with the other metals, have usually been called *amalgams*, and we see no inconvenience from continuing the use of that term

Sulphur, phosphorus, and charcoal readily unite with metals Combinations of sulphur with metals are usually named *pyrites* Their combinations with phosphorus and charcoal are either not yet named or have received new names only of late, so that we have not scrupled to change them according to our principles The combinations of metal and sulphur we call *sulphurets*, those with phosphorus *phosphurets*, and those formed with charcoal *carburets* These denominations are extended to all the combinations into which the above three substances enter, without being previously oxygenated Thus, the combination of sulphur with potash, or fixed vegetable alkali, is called *sulphuret of potash*, that which it forms with ammonia, or volatile alkali, is termed *sulphuret of ammonia*.

Hydrogen is likewise capable of combining with many combustible substances In the state of gas it dissolves charcoal, sulphur, phosphorus, and several metals, we distinguish these combinations by the terms, *carbonated hydrogen gas, sulphurated hydrogen gas*, and *phosphorated hydrogen gas* The sulphurated hydrogen gas was called *hepatic air* by former chemists, or *foetid air from sulphur*, by M Scheele The virtues of several mineral waters, and the foetid smell of animal excrements,

contact with atmospheric air, or, what is bet-

of fish in the state of putrefaction arises from the escape of this species of gas When hydrogen and charcoal are combined together, with-

the proportions of hydrogen and charcoal in its composition The chief difference between fixed or fat oils drawn from vegetables by expres-

ing combustion and are thereby converted

It is worthy of being examined whether hy-

sibility of this union Iron and zinc are the

very difficult to get entirely free from moisture in *chemical experiments it is hardly possible* to determine whether the small portions of hydrogen gas obtained in certain experiments with these metals were previously combined with the metal in the state of solid hydrogen, *or if they were produced by the decomposition* of a minute quantity of water The more care we take to prevent the presence of water in these experiments the less is the quantity of

However this inquiry may turn out respecting the power of combustible bodies, as sulphur, phosphorus, and metals, to absorb hy-

can only be considered as a foreign substance which contaminates their purity It is the province of the advocates for this system to prove, by decisive experiments the real existence of this combined hydrogen which they *have hitherto only done by conjectures founded* upon suppositions

CHAPTER XI

Observations upon Oxides and Acids with Several Bases and upon the Composition of Animal and Vegetable Substances

duce a vast variety of compounds from a very limited number of elements or simple substances

taken separately

to distinguish it by an appropriate name that

position

This phenomenon of a

acid, which had formerly been observed only in the nitro-muriatic acid, occurs continually in the vegetable kingdom, in which a simple acid, or one possessed of a single acidifiable base, is very rarely found. Almost all the acids procurable from this kingdom have bases composed of charcoal and hydrogen, or of charcoal, hydrogen, and phosphorus, combined with more or less oxygen. All these bases, whether double or triple, are likewise formed into oxides, having less oxygen than is necessary to give them the properties of acids. The acids and oxides from the animal kingdom are still more compound, as their bases generally consist of a combination of charcoal, phosphorus, hydrogen, and azote.

As it is but of late that I have acquired any clear and distinct notions of these substances, I shall not, in this place, enlarge much upon the subject, which I mean to treat of very fully in some *Mémoires* I am preparing to lay before the Academy. Most of my experiments are already performed, but, to be able to give exact reports of the resulting quantities, it is necessary that they be carefully repeated and increased in number; wherefore, I shall only give a short enumeration of the vegetable and animal acids and oxides and terminate this article by a few reflections upon the composition of vegetable and animal bodies.

Sugar, mucus, under which term we include the different kinds of gums, and starch, are

of oxygen, and, according to the degrees of oxygenation, and the proportion of hydrogen and charcoal, in their bases, they form the several kinds of vegetable acids.

they would thus become hydro-carbonous acids and oxides. In this method we might indicate which of their elements existed in excess, with-

the formerly established rules of our nomenclature, we have the following denominations: *hydro-carbonous*, *hydro-carbonic*, *carbono-hydrous*, and *carbono-hydric* oxides. And for the acids: *hydro-carbonous*, *hydro carbonic*, *oxygenated hydro-carbonic*, *carbono-hydrous*, *carbono-hydric*, and *oxygenated carbono-hydric*. It is probable that the above terms would suffice for indicating all the varieties in nature, and that, in proportion as the vegetable acids become well understood, they will naturally arrange themselves under these denominations. But, though we know the elements of which these are

the prop

still far

above methodical manner, wherefore, we have determined to retain the ancient names provisionally. I am somewhat further advanced in this inquiry than at the time of publishing our conjunct essay upon chemical nomenclature, yet it would be improper to draw decided consequences from experiments not yet sufficiently precise. Though I acknowledge that this part of chemistry still remains in some degree obscure, I must express my expectations of its being very soon elucidated.

bases, of these we have a considerable number from the animal kingdom, and some even from vegetable substances. Azote, for instance, joined to hydrogen and charcoal forms the base or radical of prussic acid; we have reason to believe that the same happens with the base of gallic acid, and almost all the animal acids have their bases composed of azote, phosphorus, hydrogen, and charcoal. Were we to endeavour to express at once all these four component parts of the bases, our nomenclature would undoubtedly be methodical, it would

from that accuracy it must arrive to, the perfection of the science ought certainly to precede that of its language, and we must still, for some time, retain the old names for the animal oxides and acids. We have only ventured to make a few slight modifications of these names, by changing the termination into

ous when we have reason to suppose the base to be in excess, and into *ic* when we suspect the oxygen predominates

The following are all the vegetable acids hitherto known

1 Acetous acid	8 Pyro mucous acid
2 *Acetic acid*	9 *Pyro-lignous acid*
3 Oxalic acid	10 Gallic acid
4 Tartarous acid	11 Benzoic acid
5 Pyro tartarous acid	12 Camphoric acid
6 Citric acid	13 Succinic acid
7 Malic acid	

Though all these acids, as has been already said, are chiefly, and almost entirely, composed of hydrogen, charcoal, and oxygen, yet, properly speaking, they contain neither water, carbonic acid, nor oil but only the elements necessary for forming these substances The power of affinity reciprocally exerted by the hydrogen, charcoal, and oxygen in these acids is in a state of equilibrium only capable of existing in the ordinary temperature of the atmosphere for, when they are heated but a very little above the temperature of boiling water this *equilibrium is destroyed, part of the oxygen and hydrogen unite and form water*, *part of* the charcoal and hydrogen combine into oil part of the charcoal and oxygen unite to form carbonic acid and lastly, there generally remains a small portion of charcoal, which, being in excess with respect to the other ingredients, is left free I mean to explain this subject some-

mined The red part of the blood lymph, and

approach very near each other in their nature, or, at least, differ only in a scarcely sensible degree I do not include the phosphoric acid *amongst these, because it is found in all the* kingdoms of nature They are

1 Lactic acid	4 Formic acid
2 Saccho-lactic acid	5 Sebacic acid
3 Bombic acid	6 Prussic acid

The connection between the constituent elements of the animal oxides and acids is not

CHAPTER XII

Of the Decomposition of Vegetable and Animal Substances by the Action of Fire

Before we can thoroughly comprehend what takes place during the decomposition of vegetable substances by fire, *we must take into* consideration the nature of the elements which enter into their composition, the different affinities which the particles of these elements exert upon each other, and the affinity which caloric possesses with them The true constituent elements of vegetables are hydrogen, oxygen, and charcoal these are common to all vegetables, and no vegetable can exist without them Such other substances as exist in particular vegetables are only essential to the composition of those in which they are found and do not belong to vegetables in general

Of these elements, hydrogen and oxygen have a strong tendency to unite with caloric and be converted into gas, whilst charcoal is a fixed element having but little affinity with caloric On the other hand, oxygen, which, in *the usual temperature, tends nearly equally to unite with hydrogen and with charcoal*, has a much stronger affinity with charcoal when at red heat[1] and then unites with it to form carbonic acid

Although we are far from being able to appreciate all these powers of affinity, or to express their proportional energy by numbers, we are certain that however variable they may be when considered in relation to the quantity of caloric with which they are combined they are all nearly in equilibrium in the usual temperature of the atmosphere, hence vegetables neither contain oil[2] water, nor carbonic acid, tho they contain all the elements of these substances The hydrogen is neither combined *with the oxygen nor with the charcoal and reciprocally*, the particles of these three substances form a triple combination which remains in equilibrium whilst undisturbed by caloric, *but a very slight increase of temperature is suf*

ficient to overturn this structure of combination

If the increased temperature to which the

the charcoal and forms volatile oil, whilst the remainder of the charcoal, being set free from its combination with the other elements, remains fixed in the bottom of the distilling vessel

When, on the contrary, we employ red heat, no water is formed, or, at least any that may

gree of heat combines with it to form carbonic acid, and the hydrogen being left free from combination with the other elements unites with caloric and escapes in the state of hydrogen gas In this high temperature, either no oil is formed, or, if any was produced during the lower temperature at the beginning of the experiment, it is decomposed by the action of the red heat Thus the decomposition of vegetable matter, under a high temperature, is produced by the action of double and triple affinities, while the charcoal attracts the oxygen on purpose to form carbonic acid the caloric attracts the hydrogen and converts it into hydrogen gas

[illegible]

upon raising the heat only a little above that degree, it becomes blackened, a part of the charcoal separates from the combination, water slightly acidulated passes over accompanied by a little oil, and the charcoal which remains in the retort is nearly a third part of the original weight of the sugar

The operation of affinities which take place during the decomposition, by fire, of vegetables which contain azote, such as the cruciferous plants, and of those containing phosphorus, is more complicated, but, as these substances only enter into the composition of vegetables in very small quantities they only, apparently, produce slight changes upon the products of distillation, the phosphorus seems to combine with the charcoal and, acquiring fixity from that union, remains behind in the retort, while the azote, combining with a part of the hydrogen, forms ammonia or volatile alkali

Animal substances, being composed nearly of the same elements with cruciferous plants, give the same products in distillation, with this difference that, as they contain a greater quantity of hydrogen and azote, they produce more oil and more ammonia I shall only produce one fact as a proof of the exactness with which this theory explains all the phenomena which occur during the distillation of animal substances, which is the rectification and total decomposition of volatile animal oil, commonly known by the name of Dippel's oil When these oils are procured by a first distillation in a naked fire they are brown, from containing a little charcoal almost in a free state, but they become quite colourless by rectification Even in this state the charcoal in their composition has so slight a connection with the other elements as to separate by mere exposure to the air If we put a quantity of this animal oil, well rectified, and consequently clear, limpid, and transparent, into a bell glass filled with oxygen gas over mercury, in a short time the gas is much diminished, being absorbed by the oil, the oxygen combining with the hydrogen of the oil forms water which sinks to the bottom, at the same time the charcoal which was combined with the hydrogen, being set free, manifests itself by rendering the oil black Hence the only way of preserving these oils colourless and transparent, is by keeping them in bottles perfectly full and accurately corked, to hinder the contact of air, which always discolours them

Successive rectifications of this oil furnish another phenomenon confirming our theory In each distillation a small quantity of charcoal remains in the retort, and a little water is formed by the union of the oxygen contained in the air of the distilling vessels with the hydrogen of the oil As this takes place in each successive distillation, if we make use of large vessels and a considerable degree of heat, we at last decompose the whole of the oil and change it entirely into water and charcoal When we use small vessels, and especially when we employ a slow fire or degree of heat little above that of boiling water, the total decomposition of these oils, by repeated distillation,

but what I have related above may suffice to give just ideas of the composition of animal

and vegetable substances and of their decomposition by the action of fire

CHAPTER XIII

Of the Decomposition of Vegetable Oxides by the Vinous Fermentation

THE manner in which wine, cider, mead, and all the liquors formed by the spiritous fermentation, are produced is well known to everyone The juice of grapes or of apples being expressed, and the latter being diluted with water, they are put into large vats which are kept in a temperature of at least 10° (54 5°) of the thermometer A rapid intestine motion, or fermentation, very soon takes place, numerous

gathered, it is found to be carbonic acid perfectly pure and free from admixture with any other species of air or gas whatever

When the fermentation is completed, the

known in commerce under the name of *spirit of wine* As this liquor is produced by the fermentation of any saccharine matter whatever diluted with water it must have been contrary to the principles of our nomenclature to call it spirit of wine rather than spirit of cider or of fermented sugar, wherefore we have adopted a more general term, and the Arabic word *alcohol* seems extremely proper for the purpose

This operation is one of the most extraordinary in chemistry We must examine whence

precisely the same and nothing takes place beyond changes and modifications in the combination of these elements Upon this principle the whole art of performing chemical experiments depends We must always suppose an exact equality between the elements of the body examined and those of the products of its analysis

Hence since from must of grapes we procure alcohol and carbonic acid, I have an undoubted right to suppose that must consists of carbonic acid and alcohol From these premises we have two methods of ascertaining what passes during vinous fermentation, by determining the nature of, and the elements which compose the fermentable substances, or by accurately examining the products resulting from fermentation, and it is evident that the knowledge of either of these must lead to accurate conclusions concerning the nature and composition of the other From these considerations, it became necessary accurately to determine the constituent elements of the fermentable substances and for this purpose, I did not make

train of experiments made in various ways, and often repeated I ascertained that the proportion in which these ingredients exist in sugar are nearly eight parts of hydrogen 64

duced by calculation

TABLE I *Materials of Fermentation*

		lbs	*oz*	*gros*	*grs*
Water		400	0	0	0
Sugar		100	0	0	0
Yeast in paste, 10 *lbs* composed of	Water	7	3	6	44
	Dry yeast	2	12	1	28
	Total	510	0	0	0

TABLE II *Constituent Elements of the Materials of Fermentation*

		lbs	*oz*	*gros*	*grs*
407 *lbs* 3 *oz* 6 *gros* 44 *grs* of water composed of	Hydrogen	61	1	2	71 40
	Oxygen	346	2	3	44 60
100 *lbs* sugar composed of	Hydrogen	8	0	0	0
	Oxygen	64	0	0	0
	Charcoal	28	0	0	0
2 *lbs* 12 *oz* 1 *gros* 28 *grs* of dry *yeast* composed of	Hydrogen	0	4	5	9 30
	Oxygen	1	10	2	28 76
	Charcoal	0	12	4	59
	Azote	0	0	5	2 94
	Total	510	0	0	0

TABLE III *Recapitulation of these Elements*

		lbs	*oz*	*gros*	*grs*	*lbs*	*oz*	*gros*	*grs.*
Oxygen	*of water*	340	0	0	0	411	12	6	1 36
	of water in yeast	6	2	3	44 60				
	of sugar	64	0	0	0				
	of dry yeast	1	10	2	28 76				
Hydrogen	of water	60	0	0	0	69	6	0	8 70
	of water in yeast	1	1	2	71 40				
	of sugar	8	0	0	0				
	of dry yeast	0	4	5	9 30				
Charcoal	of sugar	28	0	0	0	28	12	4	59 00
	of yeast	0	12	4	59.00				
Azote of yeast						0	0	5	2 94
				Total		510	0	0	0

Having thus accurately determined the nature *and quantity of the constituent elements* of the materials submitted to fermentation, we *have next to examine the products resulting* from that process For this purpose, I placed the above 510 *lbs* of fermentible liquor in a proper[1] apparatus, by means of which I could accurately determine the quantity and quality *of gas disengaged during the fermentation, and* could even weigh every one of the products separately, at any period of the process I judged proper *An hour or two after the substances* are mixed together, especially if they are kept in a temperature of from 15° (65 75°) to 18° (72 5°) of the thermometer, the first marks of *fermentation commence the liquor turns thick* and frothy, little globules of air are disengaged *which rise and burst at the surface, the quan*tity of these globules quickly increases, and there is a rapid and abundant production of very pure carbonic acid, accompanied with a scum which is the yeast separating from the mixture *After some days, less or more accord*ing to the degree of heat, the intestine motion and disengagement of gas diminish, but these *do not cease entirely, nor is the fermentation* completed for a considerable time During the process, 35 *lbs* 5 *oz* 4 *gros* 19 *grs* of dry carbonic acid are disengaged, which carry alongst with them 13 *lbs* 14 *oz* 5 *gros* of water There

[1] The above apparatus is described in the Third *Part* —AUTHOR

remains in the vessel 460 *lbs* 11 *oz* 6 *gros* 53 [illegible]

de l Académie

TABLE IV *Products of Fermentation*

		lbs	*oz*	*gros*	*grs*
35 *lbs* 5 *oz* 4 *gros* 19 *grs* of carbonic acid composed of	Oxygen	25	7	1	34
	Charcoal	9	14	2	57
408 *lbs* 15 *oz* 5 *gros* 14 *grs* of water composed of	Oxygen	347	10	0	59
	Hydrogen	61	5	4	27
[illegible]	Oxygen [illegible]	31	6	1	64
	[illegible]	5	8	5	3
	[illegible]	4	0	5	0
	with hydrogen	16	11	5	63
2 *lbs* 8 *oz* of dry acetous acid composed of	Hydrogen	0	2	4	0
	Oxygen	1	11	4	0
	Charcoal	0	10	0	0
4 *lbs* 1 *oz* 4 *gros* 3 *grs* of residuum of sugar composed of	Hydrogen	0	5	1	67
	Oxygen	2	9	7	27
	Charcoal	1	2	2	53
1 *lb* 6 *oz* 0 *gros* 5 *grs* of dry yeast composed of	Hydrogen	0	2	2	41
	Oxygen	0	13	1	14
	Charcoal	0	6	2	30
	Azote	0	0	2	37
510 *lbs*	Total	510	0	0	0

TABLE V *Recapitulation of the Products*

		lbs	*oz*	*gros*	*grs*
409 *lbs* 10 *oz* 0 *gros* 54 *grs* of oxygen contained in the	Water	347	10	0	59
	Carbonic acid	25	7	1	34
	Alcohol	31	6	1	64
	Acetous acid	1	11	4	0
	Residuum of sugar	2	9	7	27
	Yeast	0	13	1	14
28 *lbs* 12 *oz* 5 *gros* 59 *grs* of charcoal contained in the	Carbonic acid	9	14	2	57
	Alcohol	16	11	5	63
	Acetous acid	0	10	0	0
	Residuum of sugar	1	2	2	53
	Yeast	0	6	2	30
71 *lbs* 8 *oz* 6 *gros* 66 *grs* of hydrogen contained in the	Water	61	5	4	27
	Water of the alcohol	5	8	5	3
	Combined with the charcoal of the alcohol	4	0	5	0
	Acetous acid	0	2	4	0
	Residuum of sugar	0	5	1	67
	Yeast	0	2	2	41
2 *gros* 37 *grs* of azote in the yeast		0	0	2	37
510 *lbs*	Total	510	0	0	0

In these results I have been exact, even to grains, not that it is possible, in experiments of this nature, to carry our accuracy so far, but as the experiments were made only with a few pounds of sugar, and as, for the sake of comparison, I reduced the results of the actual experiments to the quintal or imaginary hundred pounds, I thought it necessary to leave the fractional parts precisely as produced by calculation

When we consider the results presented by these tables with attention, it is easy to discover exactly what occurs during fermentation In the first place, out of the 100 *lbs* of sugar employed 4 *lbs* 1 *oz* 4 *gros* 3 *grs* remain, without having suffered decomposition, so that, in reality, we have only operated upon 95 *lbs* 14 *oz* 3 *gros* 69 *grs* of sugar, that is to say, upon 61 *lbs* 6 *oz* 45 *grs* of oxygen, 7 *lbs* 10 *oz* 6 *gros* 6 *grs* of hydrogen, and 26 *lbs* 13 *oz* 5 *gros* 19 *grs of charcoal By comparing these quantities*, we find that they are fully sufficient for forming the whole of the alcohol, carbonic acid and acetous acid produced by the fermentation It is not, therefore, necessary to suppose that any water has been decomposed during the experiment, unless it be pretended that the oxygen and hydrogen exist in the sugar in that state On the contrary, I have already made it evident that hydrogen oxygen and charcoal, the three constituent elements of vegetables, remain in a state of equilibrium or mutual union with each other which subsists so long as this union remains undisturbed by increased temperature or by some new compound attraction and that then only these elements combine, two and two together, to form water and carbonic acid

The effects of the vinous fermentation upon sugar is thus reduced to the mere separation of its elements into two portions, one part is oxygenated at the expense of the other so as to form carbonic acid, whilst the other part, being disoxygenated in favour of the former, is converted into the combustible substance alcohol, therefore, if it were possible to reunite alcohol and carbonic acid together, we ought to form sugar It is evident that the charcoal and hydrogen in the alcohol do not exist in the state of oil They are combined with a portion of oxygen, which renders them miscible with water, wherefore these three substances, oxygen, hydrogen, and charcoal, exist here likewise in a species of equilibrium or reciprocal combination, and in fact, when they are made to pass through a red hot tube of glass or porcelain, this union or equilibrium is destroyed, the elements become combined, two and two, and water and carbonic acid are formed

I had formally advanced, in my first *Mémoires* upon the formation of water, that it was decomposed in a great number of chemical experiments and particularly during the vinous fermentation I then supposed that water existed ready formed in sugar, though I am now convinced that sugar only contains the elements proper for composing it It may be readily conceived that it must have cost me a good deal to abandon my first notions, but by several years reflection, and after a great number of experiments and observations upon vegetable substances, I have fixed my ideas as above

I shall finish what I have to say upon vinous fermentation by observing that it furnishes us with the means of analysing sugar and every *vegetable fermentable matter We may con*sider the substances submitted to fermentation, and the products resulting from that operation, as forming an algebraic equation and, by successively supposing each of the elements in this equation unknown, we can calculate their values in succession, and thus verify our experiments by calculation, and our calculation by experiment reciprocally I have often successfully employed this method for correcting the first results of my experiments and to direct me in the proper road for repeating them to advantage I have explained myself at large upon this subject, in a *Mémoire* upon vinous fermentation already presented to the Academy which will speedily be published

CHAPTER XIV

Of the Putrefactive Fermentation

THE phenomena of putrefaction are caused, like those of vinous fermentation, by the operation of very complicated affinities The constituent elements of the bodies submitted to this process cease to continue in equilibrium in the threefold combination and form themselves anew into binary combinations, or compounds, consisting of two elements only but these are entirely different from the results produced by the vinous fermentation Instead of one part of the hydrogen remaining united with part of the water and charcoal to form alcohol, as in the vinous fermentation, the whole of the hydrogen is dissipated, during putrefaction, in the form of hydrogen gas, whilst, at the same

time the oxygen and charcoal uniting with caloric escape in the form of carbonic acid gas so that when the whole process is finished especially if the materials have been mixed with a sufficient quantity of water nothing remains but the earth of the vegetable mixed with a small portion of charcoal and iron Thus putrefaction is nothing more than a complete

Such is the result of putrefaction when the

imperfectly and with difficulty and require a considerable time to complete their putrefaction It is otherwise with substances containing azote which indeed exists in all animal matters and even in a considerable number of

ing composts and dunghills for the purposes of agriculture consists in the proper application of this admixture

The addition of azote to the materials of putrefaction not only accelerates the process that element likewise combines with part of the hydrogen and forms a new substance called *volatile alkali* or *ammonia* The results obtained by analysing animal matters by different processes leave no room for doubt with regard to the constituent elements of ammonia when ever the azote has been previously separated from these substances no ammonia is produced and in all cases they furnish ammonia *only* in proportion to the azote they contain This composition of ammonia is likewise fully proved by M Berthollet in the *Recueil de l Académie* for 1785 p 316 where he gives a variety of analytical processes by which ammonia is decomposed and its two elements

quality in an eminent degree it dissolves charcoal sulphur and phosphorus producing the compounds named *carbonated hydrogen gas* *sulphurated hydrogen gas* and *phosphorated hy*

has likewise a peculiar odour not less penetrating or less disagreeable than these other gases From the mixture of these different flavours proceeds the fetor which accompanies the putrefaction of animal substances Sometimes ammonia predominates which is easily perceived by its sharpness upon the eyes sometimes as in feculent matters the sulphurated gas is most prevalent and sometimes as in putrid herrings the phosphorated hydrogen gas is most abundant

I long supposed that nothing could derange or interrupt the course of putrefaction but M Fourcroy and M Thouret have observed some peculiar phenomena in dead bodies

contained in the animal substance by some unknown cause leaving only the hydrogen and charcoal remaining which are the elements proper for producing fat or oil This observation upon the possibility of converting animal substances into fat may some time or other lead to discoveries of great importance

way than as manures

composed of hydrogen, charcoal azote phos

[1] In the Third Part will be given the description of an apparatus proper for being used in experiments of this kind.—AUTHOR.

CHAPTER XV

Of the Acetous Fermentation

The acetous fermentation is nothing more than the acidification or oxygenation of wine, produced in the open air by means of the absorption of oxygen The resulting acid is the acetous acid, commonly called *vinegar*, which is composed of hydrogen and charcoal united together in proportions not yet ascertained and changed into the acid state by oxygen As vinegar is an acid, we might conclude from analogy that it contains oxygen, but this is put beyond doubt by direct experiments in the first place, we cannot change wine into vinegar without the contact of air containing oxygen, secondly, this process is accompanied by a diminution of the volume of the air in which it is carried on from the absorption of its oxygen and, thirdly, wine may be changed into vinegar by any other means of oxygenation

Independent of the proofs which these facts furnish of the acetous acid being produced by the oxygenation of wine, an experiment made by M Chaptal, Professor of Chemistry at Montpellier, gives us a distinct view of what takes place in this process He impregnated water with about its own bulk of carbonic acid from fermenting beer and placed this water in a cellar in vessels communicating with the air, and in a short time the whole was converted into acetous acid The carbonic acid gas procured from beer vats in fermentation is not perfectly pure but contains a small quantity of alcohol in solution wherefore water impregnated with it contains all the materials necessary for forming the acetous acid The alcohol furnishes hydrogen and one portion of charcoal, the carbonic acid furnishes oxygen and the rest of the charcoal, and the air of the atmosphere furnishes the rest of the oxygen necessary for changing the mixture into acetous acid From this observation it follows that nothing but hydrogen is wanting to convert carbonic acid into acetous acid, or more generally that, by means of hydrogen and according to the degree of oxygenation, carbonic acid may be changed into all the vegetable acids, and, on the contrary, that, by depriving any of the vegetable acids of their hydrogen, they may be converted into carbonic acid

Although the princip[illegible] acetous [illegible] ac[illegible] ex[illegible] wh[illegible] [illegible]y farther upon the subject It is sufficiently shown by what has been said that the constitution of all the vegetable acids and oxides is exactly conformable to the formation of vinegar, but further experiments are necessary to teach us the proportion of the constituent elements in all these acids and oxides We may easily perceive, however, that this part of chemistry, like all the rest of its divisions, makes rapid progress towards perfection, and that it is already rendered greatly more simple than was formerly believed

CHAPTER XVI

Of the Formation of Neutral Salts and of their Different Bases

We have just seen that all the oxides and acids from the animal and vegetable kingdoms are formed by means of a small number of simple elements, or at least of such as have not hitherto been susceptible of decomposition, by means of combination with oxygen, these are azote, sulphur, phosphorus, charcoal, hydrogen, and the muriatic radical We may justly admire the simplicity of the means employed by nature to multiply qualities and forms, whether by combining three or four acidifiable bases in different proportions or by altering the dose of oxygen employed for oxidating or acidifying them We shall find the means no less simple and diversified, and as abundantly productive of forms and qualities, in the order of bodies we are now about to treat of

Acidifiable substances, by combining with oxygen and their consequent conversion into acids, acquire great susceptibility of further combination, they become capable of uniting with earthy and metallic bodies, by which means neutral salts are formed Acids may therefore be considered as true *salifying principles*, and the substances with which they unite to form neutral salts may be called *salifiable* bases The nature of the union which these two principles form with each other is meant as the subject of the present chapter

This view of the acids prevents me from considering them as salts, though they are possessed of many of the principal properties of saline bodies, as solubility in water, &c I have already observed that they are the result of a first order of combination, being composed of two simple elements, or at least of elements which act as if they were simple, and we may therefore rank them, to use the language of Stahl, in the order of *mixts* The neutral salts,

on the contrary, are of a secondary order of combination, being formed by the union of two *mixts* with each other, and may therefore be termed *compounds* Hence I shall not arrange the alkalies[1] or earths in the class of salts, to which I allot only such as are composed of an

chapter to give an account of the nature and

Of Potash

We have already shown that, when a vegetable substance is submitted to the action of fire in distilling vessels, its component elements, oxygen, hydrogen and charcoal, which formed a threefold combination in a state of equilibrium, unite, two and two, in obedience to affinities which act conformably to the degree of heat employed Thus, at the first application of the fire, whenever the heat produced exceeds the temperature of boiling water, part of

water, which had been formed in the early part of the process, become again decomposed, the oxygen and charcoal unite to form carbonic acid, a large quantity of hydrogen gas is set free, and nothing but charcoal remains in the retort

A great part of these phenomena occur during the combustion of vegetables in the open air but, in this case, the presence of the air introduces three new substances, the oxygen and azote of the air, and caloric, of which two at

of the fire, it is set on fire immediately upon getting in contact with the air, water is again formed, and the greater part of the caloric of the two gases becoming free produces flame When all the hydrogen gas is driven out, burnt, and again reduced to water, the remaining charcoal continues to burn, but without flame it is formed into carbonic acid, which carries off a portion of caloric sufficient to give it the gaseous form, the rest of the caloric, from the oxy-

principles which enter into the constitution of vegetables

The earth, or rather ashes, which seldom exceeds a twentieth part of the weight of the vegetable, contains a substance of a particular nature, known under the name of *fixed vegetable alkali* or *potash* To obtain it, water is poured upon the ashes which dissolves the potash and leaves the ashes which are insoluble by afterwards evaporating the water, we obtain the potash in a white concrete form it is very fixed even in a very high degree of heat I do not mean here to describe the art of preparing pot-

explained

The potash obtained by this process is always less or more saturated with carbonic acid, which is easily accounted for As the potash

[1] Perhaps my thus rejecting the alkalies from the class of salts may be considered as a capital defect in

of rendering air or gas dry by exposing them to its action In this state it is soluble in alcohol, though not when combined with carbonic acid, and M Berthollet employs this property as a method of procuring potash in the state of perfect purity

All vegetables yield less or more of potash in consequence of combustion but it is furnished in various degrees of purity by different vegetables, usually indeed, from all of them it is mixed with *different salts from which it is easily separable* We can hardly entertain a doubt that the ashes or earth which is left by vegetables in combustion pre-existed in them before they were burnt, forming what may be called the skeleton or osseous part of the vegetable But it is quite otherwise with potash, *this substance has never yet been procured* from vegetables but by means of processes or intermedia capable of furnishing oxygen and azote, such as combustion, or by means of nitric acid, so that it is not yet demonstrated that potash may not be a produce from these operations I have begun a series of experiments *upon this object and hope soon to be* able to give an account of their results

Of Soda

Soda, like potash, is an alkali procured by lixiviation from the ashes of burnt plants, but only from those which grow upon the seaside, and especially from the herb *kali* whence is derived the name *alkali* given to this substance by the Arabians It has some properties in common *with potash and others which are entirely* different In general these two substances have peculiar characters in their saline combinations *which are proper to each and consequently distinguish* them from each other, thus soda, which, as obtained from marine plants, is usually entirely saturated with carbonic acid, does not attract the humidity of the atmosphere like potash, but, on the contrary, desiccates, its crystals effloresce and are converted into a white powder *having all the properties of soda, which it* really is, having only lost its water of crystallization

We are not better acquainted with the constituent elements of soda than with those of potash, being equally uncertain whether it previously existed ready formed in the vegetable or is a combination of elements effected by combustion Analogy leads us to suspect that azote is a constituent element of all the alkalies, as *is the case* with ammonia, but we have only slight presumptions, unconfirmed by any decisive experiments, respecting the composition of potash and soda

Of Ammonia

We have, however, very accurate knowledge of the composition of ammonia, or volatile alkali as *it is called by the old chemists M Berthollet*, in the *Recueil de l'Académie* for 1784, p 316, has proved by analysis, that 1000 parts of this substance consist of about 807 parts of *azote combined with 193 parts of hydrogen*

Ammonia is chiefly procurable from animal substances by distillation, during which process the azote and hydrogen necessary to its formation unite in proper proportions, it is not, however, procured pure by this process, being mixed with oil and water and mostly saturated with *carbonic acid To separate these substances* it is first combined with an acid, the muriatic for instance, and then disengaged from that combination by the addition of lime or potash When ammonia is thus produced in its greatest degree of purity, it can only exist under the gaseous form, at least in the usual *temperature of the atmosphere, it has an excessively* penetrating smell, is absorbed in large quantities by water, especially if cold and *assisted by compression Water thus saturated* with ammonia has usually been termed *volatile alkaline fluor* we shall call it either simply *ammonia*, or *liquid ammonia*, and *ammoniacal gas* when it exists in the aeriform state

Of Lime, Magnesia, Barytes, and Argill

The composition of these four earths is totally unknown, and, until by new discoveries their constituent elements are ascertained, we are *certainly authorised to consider them as simple* bodies Art has no share in the production of these earths, as they are all procured ready formed from nature, but, *as they have all*, especially the three first, great tendency to combination, they are never found pure Lime is usually saturated with carbonic acid in the *state of chalk, calcareous spars*, most of the marbles, &c , sometimes with sulphuric acid, as in gypsum and plaster stones, at other times *with fluoric acid forming vitreous or fluor spars*, and, lastly, it is found in the waters of the sea, and of saline springs, combined with muriatic acid *Of all the salifiable bases it is the most* universally spread through nature.

Magnesia is found in mineral waters, for the most part combined with sulphuric acid, it is likewise abundant in sea water, united with muriatic acid, and it exists in a great number

of stones of different kinds

Barytes is much less common than the three preceding earths, it is found in the mineral kingdom, combined with sulphuric acid, forming heavy spars, and sometimes, though rarely, united to carbonic acid

Argill, or the base of alum, having less tendency to combination than the other earths, is often found in the state of argill, uncombined with any acid It is chiefly procurable from clays, of which, properly speaking it is the base or chief ingredient

Of Metallic Bodies

The metals, except gold and sometimes s[illegible]

[illegible]

carbonic acid, or phosphoric acid Metallurgy, or the docimastic art, teaches the means of separating them from these foreign matters, and for this purpose we refer to such chemical books as treat upon these operations

We are probably only acquainted as yet with a part of the metallic substances existing in nature, as all those which have a stronger affinity to oxygen than charcoal possesses are incapable of being reduced to the metallic state and, consequently, being only presented to our observation under the form of oxides, are confounded with earths It is extremely probable that barytes which we have just

[illegible]

stances we call earths may be only metallic oxides, irreducible by any hitherto known process

Those metallic bodies we are at present acquainted with, and which we can reduce to the metallic or reguline state, are the following seventeen

1	Arsenic	7	Bismuth	13	Copper
2	Molybdenum	8	Antimony	14	Mercury
3	Tungsten	9	Zinc	15	Silver
4	Manganese	10	Iron	16	Platinum
5	Nickel	11	Tin	17	Gold
6	Cobalt	12	Lead		

I only mean to consider these as salifiable bases, without entering at all upon the consideration of their properties in the arts and for the uses of society In these points of view each metal would require a complete treatise, which would lead me far beyond the bounds I have prescribed for this work

CHAPTER XVII

Continuation of the Observations upon Salifiable Bases and the Formation of Neutral Salts

It is necessary to remark that earths and alkalies unite with acids to form neutral salts without the intervention of any medium whereas metallic substances are incapable of forming this combination without being previously less or more oxygenated, strictly speaking therefore, metals are not soluble in acids but only metallic oxides Hence, when we put a metal

[illegible]

be dissolved in an acid unless the oxygen either of the acid or of the water mixed with it, has a stronger affinity to the metal than to the hydrogen or the acidifiable base, or, which amounts to the same thing, that no metallic solution can take place without a previous decomposition of the water or the acid in which it is made The explanation of the principal phenomena of metallic solution depends entirely upon this simple observation, which was overlooked even

[illegible]

acid this effervescence is produced by the dis-

[illegible]

perature it is disengaged and occasions effervescence

The second phenomenon is that when the metals have been previously oxidated they all dissolve in acids without effervescence This is easily explained because, not having now any occasion for combining with oxygen, they neither decompose the acid nor the water by which, in the former case, the effervescence is *occasioned*

A third phenomenon, which requires particular consideration, is that none of the metals produce effervescence by solution in oxygenated muriatic acid During this process the *metal, in the first place carries off the excess of* oxygen from the oxygenated muriatic acid by which it becomes oxidated, and reduces the acid to the state of ordinary muriatic acid In this case there is no production of gas, not that *the muriatic acid does not tend to exist in the* gaseous state in the common temperature, which it does equally with the acids formerly mentioned, but because this acid, which otherwise would expand into gas, finds more water *combined with the oxygenated muriatic acid* than is necessary to retain it in the liquid form hence it does not disengage like the sulphurous acid, but remains and quietly dissolves and combines with the metallic oxide previously *formed from its superabundant oxygen*

The fourth phenomenon is that metals are absolutely insoluble in such acids as have their bases joined to oxygen by a stronger affinity than these metals are capable of exerting upon that acidifying principle Hence silver, mercury, and lead, in their metallic states are insoluble in muriatic acid, but, when previously oxidated, they become readily soluble without effervescence

From these phenomena it appears that oxygen is the bond of union between metals and acids, and *from this we are led to suppose that* oxygen is contained in all substances which have a strong affinity with acids Hence it is very probable the four eminently salifiable earths contain oxygen, and their capability of uniting with acids is produced by the intermediation of that element What I have formerly noticed relative to these earths is considerably strengthened by the above considerations, viz that they may very possibly be metallic oxides, with which oxygen has a stronger affinity than with charcoal, and consequently not red - 'e by any known means

All the

contains the names of the acids according to the new nomenclature, and in the *second* column are placed the bases or radicals of these acids, with observations

	Names of the Acids	*Names of the Bases, with Observations*
1	Sulphurous	Sulphur
2	Sulphuric	
3	Phosphorous	Phosphorus
4	Phosphoric	
5	Muriatic	Muriatic radical or base, hitherto unknown
6	Oxygenated muriatic	
7	Nitrous	Azote
8	Nitric	
9	Oxygenated nitric	
10	Carbonic	Charcoal
11	Acetous	The bases *or radicals* of all these acids seem to be formed by a combination of charcoal and hydrogen and the only difference seems to be owing to the d fferent *proportions in* wh ch these elements combine *to form* their bases, and to the different doses of oxygen in their acidification A connected series of accurate experiments is still wanted upon *this subject*
12	Acetic	
13	Oxalic	
14	Tartarous	
15	Pyro-tartarous	
16	Citric	
17	Malic	
18	Pyro-lignous	
19	Pyro mucous	
20	Gallic	*Our knowledge of the bases* of these acids is hitherto imperfect we only know that they contain hydrogen and charcoal as principal elements and that *the prussic acid* contains azote
21	Prussic	
22	Benzoic	
23	Succinic	
24	Camphoric	
25	Lactic	
26	Saccho-lactic	
27	Bombic	The base of these and all the acids procured from animal substances seems to consist of charcoal hydrogen phosphor*us and azote*
28	Formic	
29	Sebacic	
30	Boracic	The bases of these two are hitherto entirely unknown
31	Fluoric	
32	Antimonic	Antimony
33	Argentic	Silver
34	Arseniac	Arsenic
35	Bismuthic	Bismuth
36	Cobaltic	Cobalt
37	Cupric	Copper
38	Stannic	Tin
39	Ferric	Iron
40	Manganic	Manganese
41	Mercuric	Mercury
42	Molybdic	Molybdenum
43	Nickolic	Nickel
44	Auric	Gold
45	Platinic	Platinum
46	Plumbic	Lead
47	Tungstic	Tungsten
48	Zincic	Zinc

In this list, which contains 48 acids, I have enumerated 17 *metallic acids hitherto very imperfectly known*, but upon which M Berthollet is about to publish a very important work It cannot be pretended that all the acids which exist in nature, or rather all the acidifiable bases, are yet discovered, but, on the other hand, there are considerable grounds for supposing that a more accurate investigation than has hitherto been attempted will diminish the number of the vegetable acids by showing that *several of these, at present considered* as distinct acids, are only modifications of others All that can be done in the present *state of our knowledge is to give a view of* chemistry as it really is and to establish fundamental principles by which such bodies as may be discovered in future may receive names in conformity with one uniform system

The known salifiable bases, or substances capable of being converted into neutral salts by union with acids, amount to 24 viz, 3 alkalies, 4 earths, and 17 metallic substances, so that, in *the present state of chemical knowledge*, the whole possible number of neutral salts amounts to 1152 This number is upon the supposition *that the metallic acids are capable of dissolving* other metals, which is a new branch of chemistry not hitherto investigated, upon which depends all the metallic combinations named *vitreous* There is reason to believe that many of these supposable saline combinations are not capable of being formed, which must greatly reduce the real number of neutral salts producible by nature and art Even if we suppose the real number to amount only to five or six hundred species of possible neutral salts it is evident that, were we to distinguish them after the manner of the ancients, either by the names *of their first discoverers or by terms derived* from the substances from which they are procured, we should at last have such a confusion *of arbitrary designations as no memory could possibly retain This method might be tolerable* in the early ages of chemistry, or even till within these *twenty years, when only about* thirty species of salts were known, but, in the present times, when the number is augmenting daily, when every *new acid gives us 24 or 48* new salts according as it is capable of one or two degrees of oxygenation, a new method is certainly necessary *The method we have adopted*, drawn from the nomenclature of the acids, is perfectly analogical and, following nature in the simplicity of her operations, gives a natural and easy nomenclature applicable to every *possible neutral salt*

In giving names to the different acids, we express the common property by the generical term *acid* and distinguish each species by the name of its peculiar acidifiable base Hence the acids formed by the oxygenation of sulphur, phosphorus, charcoal, &c are called *sulphuric acid, phosphoric acid, carbonic acid, &c* We thought it likewise proper to indicate the different degrees of saturation with oxygen by *different terminations of the same specific* names Hence we distinguish between sulphurous and sulphuric, and between phosphorous and phosphoric acids, &c

By applying these principles to the nomenclature of neutral salts, we give a common term to all the neutral salts arising from the combination of one acid and distinguish the species by adding the name of the salifiable base Thus, all the neutral salts having sulphuric acid in their composition are named *sulphates* those formed by the phosphoric acid, *phosphates*, &c The species being distinguished by the names of the salifiable bases gives us *sulphate of pot ash, sulphate of soda, sulphate of ammoniac, sulphate of lime, sulphate of iron*, &c As we are acquainted with 24 salifiable bases, alkaline, earthy, and metallic, we have consequently 24 sulphates, as many phosphates, and so on through all the acids Sulphur is however, susceptible of two degrees of oxygenation, the first of which produces sulphurous and the second, sulphuric acid and, as the neutral salts produced by these two acids have different properties and are in fact different salts, it becomes necessary to distinguish these by peculiar terminations, we have therefore distinguished the neutral salts formed by the acids in the first or lesser degree of oxygenation by changing the *termination ate into ite, as sulphites, phosphites*, &c Thus, oxygenated or acidified sulphur, in its two degrees of oxygenation is capable of *forming* 48 neutral salts 24 of which are sulphites, and as many sulphates, which is likewise the case with all the acids capable of two degrees of oxygenation.

It were both tiresome and unnecessary to follow these denominations through all the varieties of their possible application, it is enough to have given the method of naming the various salts which, when once well understood, is easily applied to every possible combination The name of the combustible and acidifiable body being once known, the names of the acid it is capable of forming, and of all the neutral

combinations the acid is susceptible of entering into, are most readily remembered Such as require a more complete illustration of the methods in which the new nomenclature is applied will, in *the second part of this book*, find tables which contain a full enumeration of all the neutral salts and, in general, all the possible chemical combinations, so far as is consistent with *the present state of our knowledge. To these I* shall subjoin short explanations, containing the best and most simple means of procuring the different species of acids, and some account of the general properties of the neutral salts *they produce*

I shall not deny that, to render this work more complete, it would have been necessary to add particular observations upon each species of salt, its solubility in water and alcohol, the proportions of acid and of salifiable base in its composition the quantity of its water of crystallization, the different degrees of saturation it is susceptible of, and finally, the degree *of force or affinity with which the acid adheres* to the base. This immense work has been already begun by MM Bergman, Morveau, Kirwan, and other celebrated chemists, but is hitherto only in a moderate state of advancement, even the principles upon which it is founded *are not perhaps sufficiently accurate*

These numerous details would have swelled this elementary treatise to much too great a size, besides that, to have gathered the necessary *materials, and to have completed all the* series of experiments requisite must have retarded the publication of this book for many years This is a vast field for employing the zeal and abilities of young chemists, whom I would advise *to endeavour rather to do well* than to do much, and to ascertain, in the first place, the composition of the acids, before entering upon that of the neutral salts Every edifice which is intended to resist *the ravages of time should be built upon a sure foundation,* and, in the present state of chemistry, to attempt discoveries by experiments either not perfectly exact or not sufficiently rigorous, will *serve only to interrupt its progress, instead of* contributing to its advancement

SECOND PART

Of the combination of acids with salifiable bases, and of the formation of neutral salts

INTRODUCTION

If I had strictly followed the plan I at first laid down for the conduct of this work, I would have confined myself, in the tables and accompanying observations which compose this second part, to short definitions of the several known acids and abridged accounts of the processes by which they are obtainable, with a mere

But I afterwards found that the addition of similar tables of all the simple substances which enter into the composition of the acids and oxides, together with the various possible combinations of these elements, would add greatly to the utility of this work without being any great increase to its size These additions, which are all contained in the twelve first sections of this part and the tables annexed to these, form a kind of recapitulation of the first fifteen chapters of the first part The rest of the tables and sections contain all the saline combinations

It must be very apparent that, in this part of the work, I have borrowed greatly from what has been already published by M de Morveau in the first volume of the *Encyclopedie par ordre des Matières* I could hardly have discovered a better source of information, especially when the difficulty of consulting books in foreign languages is considered I make this general acknowledgment on purpose to save the trouble of references to M de Morveau's work in the course of the following part of mine

Table *of Simple Substances Belonging to All the Kingdoms of Nature, Which May Be Considered as the Elements of Bodies*

New Names	*Old Names*
Light	Light
Caloric	Heat Principle or element of heat Fire Igneous fluid Matter of fire and of heat
Oxygen	Dephlogisticated air Empyreal air Vital air, or base of vital air
Azote	Phlogisticated air or gas Mephitis, or its base
Hydrogen	Inflammable air or gas, or the base of inflammable air

Oxidable and Acidifiable Simple Substances Not Metallic

New Names	*Old Names*
Sulphur Phosphorus Charcoal	The same names
Muriatic radical Fluoric radical Boracic radical	Still unknown

TABLE *of Simple Substances, Continued*
Oxidable and Acidifiable Simple Metallic Bodies

New Names		*Old Names*
Antimony	Regulus of	Antimony
Arsenic		Arsenic
Bismuth		Bismuth
Cobalt		Cobalt
Copper		Copper
Gold		Gold
Iron		Iron
Lead		Lead
Manganese		Manganese
Mercury		Mercury
Molybdenum		Molybdenum
Nickel		Nickel
Platinum		Platinum
Silver		Silver
Tin		Tin
Tungsten		Tungsten
Zinc		Zinc

Salifiable Simple Earthy Substances

New Names	*Old Names*
Lime	Chalk calcareous earth Quicklime
Magnesia	Magnesia base of Epsom salt Calcined or caustic magnesia
Barytes	Barytes or heavy earth
Argill	Clay earth of alum
Silex	Siliceous or vitrifiable earth

SECTION I

Observations upon the Table of Simple Substances

The principal object of chemical experiments is to decompose natural bodies, so as separately to examine the different substances which enter into their composition By consulting chemical systems, it will be found that this science of chemical analysis has made rapid progress in our own times Formerly oil and salt were considered as elements of bodies, whereas later observation and experiment have shown that all salts, instead of being simple, are composed of an acid united to a base The bounds of analysis have been greatly enlarged by modern discoveries[1] the acids are shown to be composed of oxygen, as an acidifying principle common to all, united in each to a particular base I have proved what M Hassenfratz had before advanced that these radicals of the acids are not all simple elements, many of them being like the oily principle, composed of hydrogen and charcoal Even the bases of neutral salts have been proved by M Berthollet to be compounds, as he has shown that ammonia is composed of azote and hydrogen

[1] See *Recueil de l Académie* for 1776 p. 671, and for 1778 p 535 —AUTHOR

TABLE *of Compound Oxidable and Acidifiable Bases*

	Names of the Radicals	
Oxidable or acidifiable base, from the mineral kingdom	Nitro-muriatic radical or base of the acid formerly called *aqua regia*	
Oxidable or acidifiable hydro-carbonous or carbono-hydrous radicals from the vegetable kingdom[1]	Tartarous radical or base	Radicals
	Malic	
	Citric	
	Pyro-lignous	
	Pyro-mucous	
	Pyro tartarous	
	Oxalic	
	Acetous	
	Succinic	
	Benzoic	
	Camphoric	
	Gallic	
Oxidable or acidifiable radicals from the animal kingdom which mostly *contain azote and frequently* phosphorus	Lactic	
	Saccholactic	
	Formic	
	Bombic	
	Sebacic	
	Lithic	
	Prussic	

[1] *Note* The radicals from the vegetable kingdom are converted by a first degree of oxygenation into vegetable oxides such as sugar starch, and gum or mucus those of the animal kingdom by the same means form animal oxides as lymph &c.—AUTHOR

Thus, as chemistry advances towards perfection, by *dividing and subdividing*, it is impossible to say where it is to end, and these things we at present suppose simple may soon be found quite otherwise. All we dare venture to affirm of any substance is that it must be considered as simple in the present state of our knowledge and so far as chemical analysis has been able to show We may even presume that the earths must soon cease to be *considered as simple bodies, they are the only* bodies of the salifiable class which have no *tendency* to unite with oxygen, and I am much inclined to believe that this proceeds from their being already saturated with that element If so, they will fall to be considered as compounds consisting of simple substances, perhaps metallic, oxidated to a certain degree. This is only hazarded as a conjecture, and I trust the reader will take care not to confound what I have related as truths, fixed on the firm basis of observation and experiment, with mere hypothetical conjectures.

The fixed alkalies, potash, and soda, are omitted in the foregoing table, because they are evidently compound substances, though we are ignorant as yet what are the elements they are composed of

SECTION II

Observations upon the Table of Compound Radicals

The *older chemists being unacquainted with* the composition of acids and not suspecting *them to be formed by a peculiar radical or* base for each, united to an acidifying principle *or element common to all, could not consequently* give any name to substances of which they had not the most distant idea We had therefore to invent a new nomenclature for this subject, though we were at the same time sensible that this nomenclature must be susceptible of great modification when the nature of the compound radicals shall be better understood[1]

The compound oxidable and acidifiable radicals from the vegetable and animal kingdoms, enumerated *in the foregoing table*, are not reducible to systematic nomenclature, *because their exact analysis is as yet* unknown. We only know in general, by some *experiments of my own and some made by* M. Hassenfratz, that most of the vegetable *acids, such as the tartarous*, oxalic, citric, malic, acetous, pyrotartarous, and pyromucous, have radicals composed of hydrogen and charcoal, combined in such a way as to form single bases, and that these acids only differ from each other by the proportions in which these two substances enter into the composition of their bases, and by the degree of oxygenation which these bases have received We *know further, chiefly from the experiments of* M Berthollet, that the radicals from the *animal* kingdom, and even some *of those* from vegetables, are of a more compound nature, and, besides hydrogen and charcoal, that they often contain azote, and sometimes phosphorus, but we were not possessed of sufficiently accurate experiments for calculating the proportions of these several substances We are therefore forced, in the manner of *the older* chemists, still to name these acids *after the* substances *from which they are* procured There can be little doubt that these names *will be laid aside when our knowledge* of these substances becomes more accurate and extensive, *the terms hydro-carbonous, hydro-carbonic, carbono-hydrous*, and *carbono-hydric*,[2] will then become substituted for those we now employ, which will then only remain as testimonies of the imperfect state in which this part of chemistry was transmitted to us by our predecessors

It is evident that the oils, being composed of hydrogen and charcoal combined, are true carbono-hydrous or hydro-carbonous radicals, and, indeed, by adding oxygen, they are convertible *into vegetable oxides and acids according to* their degrees of oxygenation. We cannot, however, *affirm that oils enter in their entire state* into the composition of vegetable oxides and acids, it is possible that they *previously lose a* part either of their hydrogen or charcoal, and that the remaining ingredients no longer exist in the proportions necessary to constitute oils. We still require further experiments to elucidate these points

Properly speaking, we are only acquainted with one compound radical from the mineral kingdom, the nitro-muriatic, which is formed by the combination of azote with the muriatic radical. The other compound mineral acids have been much less attended to, from their producing less striking phenomena

[1]See Part 1 Chapter XI upon this subject —AUTHOR.

[2]See Part I Chapter XI upon the application of these names according to the proportions of the two *ingredients* —AUTHOR.

TABLE of *Binary Combinations of Oxygen With Simple Substances*

	Simple Substances	First degree of Oxygenation: New Names	First degree of Oxygenation: Old Names	Second Degree: New Names	Second Degree: Old Names	Third Degree: New Names	Third Degree: Old Names	Fourth Degree: New Names
Combinations of oxygen with simple non-metallic substances	Caloric	Oxygen gas	Vital or dephlogisticated air					
	Hydrogen	Water[1]						
	Azote	Nitrous oxide or base of nitrous gas	Nitrous gas or air	Nitrous acid	Smoking nitrous acid	Nitric acid	Pale or non smoking nitrous acid	Oxygenated nitric acid
	Charcoal	Oxide of charcoal or carbonic oxide	Unknown	Carbonous acid	Unknown	Carbonic acid	Fixed air	—— carbonic acid
	Sulphur	Oxide of sulphur	Soft sulphur	Sulphurous acid	Sulphurous acid	Sulphuric acid	Vitriolic acid	—— sulphuric acid
	Phosphorus	Oxide of phosphorus	Residuum from the combustion of phosphorus	Phosphorous acid	Volatile acid of phosphorus	Phosphoric acid	Phosphoric acid	—— phosphoric acid
	Muriatic radical	Muriatic oxide	Unknown.	Muriatous acid	Unknown.	Muriatic acid	Marine acid.	—— muriatic acid *Old Name* Dephlogisticated marine acid
	Fluoric radical	Fluoric oxide	Unknown.	Fluorous acid	Unknown	Fluoric acid	Unknown till lately	
	Boracic radical	Boracic oxide	Unknown	Boracous acid	Unknown.	Boracic acid	Homberg's sedative salt	
Combinations of oxygen with simple metallic substances	Antimony	Grey oxide of antimony	Grey calx of antimony	White oxide of antimony	White calx of antimony diaphoretic antimony	Antimonic acid		
	Silver	Oxide of silver	Calx of silver			Argentic acid		
	Arsenic	Grey oxide of arsenic	Grey calx of arsenic	White oxide of arsenic	White calx of arsenic	Arseniac acid	Acid of arsenic	—— arseniac acid
	Bismuth	Grey oxide of bismuth	Grey calx of bismuth	White oxide of bismuth	White calx of bismuth	Bismuthic acid		
	Cobalt	Grey oxide of cobalt	Grey calx of cobalt			Cobaltic acid		
	Copper	Brown oxide of copper	Brown calx of copper	Blue and green oxides of copper	Blue and green calces of copper	Cupric acid		
	Tin	Grey oxide of tin	Grey calx of tin	White oxide of tin	White calx of tin or putty of tin	Stannic acid		
	Iron	Black oxide of iron	Martial ethiops	Yellow and red oxides of iron	Ochre and rust of iron	Ferric acid		
	Manganese	Black oxide of manganese.	Black calx of manganese	White oxide of manganese	White calx of manganese	Manganesic acid		
	Mercury	Black oxide of mercury	Ethiops mineral	Yellow and red oxides of mercury	Turbith mineral, red precipitate calcined mercury precipitate per se	Mercuric acid		
	Molybdenum	Oxide of molybdenum	Calx of molybdenum.			Molybdic acid	Acid of molybdenum	—— molybdic acid
	Nickel	Oxide of nickel	Calx of nickel			Nickelic acid		
	Gold	Yellow oxide of gold	Yellow calx of gold	Red oxide of gold	Red calx of gold purple precipitate of cassius	Auric acid		
	Platinum	Yellow oxide of platinum.	Yellow calx of platinum			Platinic acid		
	Lead	Grey oxide of lead	Grey calx of lead	Yellow and red oxides of lead	Massicot and minium	Plumbic acid		
	Tungsten	Oxide of tungsten	Calx of tungsten.			Tungstic acid	Acid of tungsten'	—— tungstic acid
	Zinc	Grey oxide of zinc	Grey calx of zinc	White oxide of zinc	White calx of zinc pompholix	Zincic acid		

[1]Only one degree of oxygenation of hydrogen is known —AUTHOR

SECTION III

Observations upon the Combinations of Light and Caloric with Different Substances

I have not constructed any table of the combinations of light and caloric with the various simple and compound substances, because our conceptions of the nature of these combinations are not hitherto sufficiently accurate. We know, in general, that all bodies in nature are imbued, surrounded, and penetrated in every way with caloric, which fills up every interval left between their particles; that, in certain cases, caloric becomes fixed in bodies, so as to constitute a part even of their solid substance, though it more frequently acts upon them with a repulsive force, from which, or from its accumulation in bodies to a greater or lesser degree, the transformation of solids into fluids, and of fluids to aeriform elasticity, is entirely owing. We have employed the generic name *gas to indicate this aeriform state of bodies* produced by a sufficient accumulation of caloric, *so that, when we wish to express the aeriform* state of muriatic acid, carbonic acid, hydrogen, water, alcohol, &c. we do it by adding the word gas to their names; thus muriatic acid gas, carbonic acid gas, hydrogen gas, aqueous gas, alcoholic gas, &c.

The combinations of light, and its mode of acting upon different bodies, is still less known. By the experiments of M. Berthollet, it appears to have great affinity with oxygen, is susceptible of combining with it, and contributes alongst with caloric to change it into the state of gas. Experiments upon vegetation give reason to believe that light combines with certain parts of vegetables, and that the green of their leaves, and the various colours of their flowers, is chiefly owing to this combination. This much is certain, that plants which grow in darkness are perfectly white, languid, and unhealthy, and that to make them recover vigour, and to acquire their natural colours, the direct influence of light is absolutely necessary. Something similar takes place even upon animals: mankind degenerate to a certain degree when employed in sedentary manufactures, from living in crowded houses or in the narrow lanes of large cities; whereas they improve in their nature and constitution in most of the country labours which are carried on in the open air. Organization, sensation, spontaneous motion, and all the operations of life, only exist at the surface of the earth, and in places exposed to the influence of light. Without it nature itself would be lifeless and inanimate. By means of light, the benevolence of the Deity hath filled the surface of the earth with organization, sen*sation, and intelligence. The fable of Prome*theus might perhaps be considered as giving a hint of this philosophical truth, which had even presented itself to the knowledge of the ancients. I have intentionally avoided any disquisitions relative to organized bodies in this work, for which reason the phenomena of respiration, sanguification, and animal heat are not considered; but I hope, at some future time, to be able to elucidate these curious subjects.

SECTION IV

Observations upon the Combinations of Oxygen with the Simple Substances

Oxygen forms almost a third of the mass of our atmosphere, and is consequently one of the most plentiful substances in nature. All the *animals and vegetables live and grow in this* immense magazine of oxygen gas, and from it we *procure the greatest part of what we em*ploy in experiments. So great is the reciprocal affinity between this element and other substances that we cannot procure it disengaged from all combination. In the atmosphere it is united with caloric, in the state of oxygen gas, and this again is mixed with about two thirds of its weight of azotic gas.

Several conditions are requisite to enable a body to become oxygenated or to permit oxygen to enter into combination with it. In the first place, it is necessary that the particles of the body to be oxygenated shall have less reciprocal attraction with each other than they have for the oxygen, which otherwise cannot possibly combine with them. Nature, in this case, may be assisted by art, as we have it in our power to diminish the attraction of the particles of bodies almost at will by heating them, or, in other words, by introducing caloric into the interstices between their particles; and, as the attraction of these particles for *each other is diminished in the inverse ratio of* their distance, it is evident that there must be a certain point of distance of particles when the affinity they possess with each other becomes less than that they have for oxygen, and at which oxygenation must necessarily take place if oxygen be present.

We can readily conceive that the degree of heat at which this phenomenon begins must be different in different bodies. Hence, on purpose to oxygenate most bodies, especially the great-

er part of the simple substances, it is only necessary to expose them to the influence of the [illegible]

[illegible]

quires a more considerable degree of heat to oxygenate iron, copper, &c, by the dry way, or when this operation is not assisted by moisture [illegible]

[illegible]

of phosphorus in atmospheric air and of iron in oxygen gas That of sulphur is less rapid, and the oxygenation of lead, tin, and most of the metals, takes place vastly slower, and con- [illegible]

decomposed by art, perhaps even not by nature, and which consequently has only been found in the state of acid It is probable that many other substances of the mineral kingdom are necessarily oxygenated in the common temperature of the atmosphere, and that being already saturated with oxygen prevents their further action upon that element

There are other means of oxygenating simple substances besides exposure to air in a certain degree of temperature, such as by placing them in contact with metals combined with oxygen and which have little affinity with that element The red oxide of mercury is one of the best substances for this purpose, especially with bodies which do not combine with that metal In this oxide the oxygen is united with very little force to the metal, and can be driven [illegible]

genated by means of being mixed with red oxide of mercury and moderately heated The

TABLE *of the Combinations of Oxygen with the Compound Radicals*

	Names of the Radicals	*Names of the Resulting Acids* New Names	*Old Names*
	Nitro-muriatic radical	Nitro-muriatic acid	*Aqua regia*
See Note 1	Tartaric	Tartarous acid	Unknown till lately
	Malic	Malic acid	Ditto
	Citric	Citric acid	Acid of lemons
	Pyro-lignous	Pyro-lignous acid	Empyreumatic acid of wood
	Pyro-mucous	Pyro-mucous acid	Empyr acid of sugar
	Pyro-tartarous	Pyro-tartarous acid	Empyr acid of tartar
	Oxalic	Oxalic acid	Acid of sorel
	Acetic	Acetous acid *Acetic acid*	Vinegar, or acid of vinegar *Radical vinegar*
	Succinic	Succinic acid	Volatile salt of amber
	Benzoic	Benzotic acid	Flowers of benzoin
	Camphoric	Camphoric acid	Unknown till lately
	Gallic	Gallic acid	The astringent principle of vegetables
See Note 2	Lactic	Lactic acid	Acid of sour whey
	Saccholactic	Saccholactic acid	Unknown till lately
	Formic	Formic acid	Acid of ants
	Bombic	Bombic acid	Unknown till lately
	Sebacic	Sebacic acid	Ditto
	Lithic	Lithic acid	Urinary calculus
	Prussic	Prussic acid	Colouring matter of Prussian blue

Note 1 These radicals by a first degree of oxygenation form vegetable oxides as sugar starch mucus &c —AUTHOR.

Note 2 These radicals by a first degree of oxygenation form the animal oxides as lymph red part of the blood animal secretions &c —AUTHOR.

same effect may be, to a certain degree, produced by means of the black oxide of manganese, the red oxide of lead the oxides of silver, and by most of the metallic oxides if we only take care to choose such as have less affinity [illegible]

The charcoal combines with the oxygen and with caloric and escapes in form of carbonic acid gas, while the metal remains pure and revivified, or deprived of the oxygen which before combined with it in the form of oxide

All combustible substances may likewise be [illegible]

bines with the combustible body Thus species of oxygenation requires to be performed with extreme caution and only with very small quantities because as the oxygen enters into the composition of nitrates and more especially of [illegible]

combination of the oxygen with the combustible body and produces such violent explosions as are perfectly irresistible

By the humid way we can oxygenate most combustible bodies, and convert most of the [illegible]

[illegible] call it *ternary* and *quad* [illegible] combination consists of four substances united

Section V

Observations upon the Combinations of Oxygen with the Compound Radicals

I published a new theory of the nature and formation of acids in the *Recueil de l Académie* for 1776, p 671 and 1778 p 535 in which I concluded that the number of acids must be greatly larger than was till then supposed Since that time, a new field of inquiry has been opened to chemists, and instead of five or six acids which were then known near thirty new acids have been discovered, by which means the number of known neutral salts have been increased in the same proportion The nature of the acidifiable bases or radicals of the acids, and the degrees of oxygenation they are susceptible of, still remain to be inquired into I have already shown that almost all the oxidable and acidifiable radicals from the mineral [illegible]

*but is composed of at least two substances hy*drogen and charcoal and that azote and phosphorus are frequently united to these by which we have compound radicals of two three, and four bases or simple elements united [illegible]

elements of which their radicals are composed 2nd according to the proportions in which [illegible]

Crell in some very ingenious experiments, which have been verified and extended by M [illegible]

Ought we then to conclude that the oils are the radicals of the vegetable and animal acids? I have already expressed my doubts upon this subject 1st, although the oils appear to be [illegible] hydrogen and charcoal

composition of these acids equally with hydrogen and charcoal, there is no more reason for supposing them to be composed of oil rather than of water or of carbonic acid It is true that they contain the materials necessary for all these combinations, but then these do not take place in the common temperature of the atmosphere, all the three elements remain combined in a state of equilibrium which is readily destroyed by a temperature only a little above that of boiling water[1]

TABLE of the Binary Combinations of Azote with the Simple Substances

Simple Substances	*Results of the Combinations* — *New Names*	*Old Names*
Caloric	Azotic gas	Phlogisticated air, or Mephitis
Hydrogen	Ammonia	Volatile alkali
Oxygen	Nitrous oxide	Base of Nitrous gas
	Nitrous acid	Smoking nitrous acid
	Nitric acid	Pale nitrous acid
	Oxygenated nitric acid	Unknown
Charcoal		
Phosphorus	Azuret of phosphorus	Still unknown
Sulphur	Azuret of sulphur Still unknown We know that sulphur dissolves in azotic gas, forming sulphurated azotic gas	
Compound radicals	Azote combines with charcoal and hydrogen and sometimes with phosphorus, in the compound oxydable and acidifiable bases, and is generally contained in the radicals of the animal acids	
Metallic substances	Such combinations are unknown if ever discovered they will form metallic azurets as azuret of gold of silver &c.	
Lime Magnesia Barytes Argill Potash Soda	Entirely unknown If ever discovered they will form azuret of lime azuret of magnesia &c.	

SECTION VI

Observations upon the Combinations of Azote with the Simple Substances

Azote is one of the most abundant elements combined with caloric it forms azotic gas, or mephitis, which composes nearly two thirds of the atmosphere This element is always in the state of gas in the ordinary pressure and temperature, and no degree of compression or of cold has been hitherto capable of reducing it either to a solid or liquid form This is likewise one of the essential constituent elements of animal bodies, in which it is combined with charcoal and hydrogen, and sometimes with phosphorus, these are united together by a

stances may be varied, in the same way with vegetables, in three different manners 1st, according to the number of elements which enter into the composition of the base or radical, 2nd, according to the proportions of these elements, 3rd, according to the degree of oxygenation

When combined with oxygen, azote forms the nitrous and nitric oxides and acids, when with hydrogen, ammonia is produced Its combinations with the other simple elements are very little known, to these we give the name of *azurets*, preserving the termination in *uret* for all non-oxygenated compounds It is extremely probable that all the alkaline substances may hereafter be found to belong to this genus of azurets.

[1] See Part I Chapter XII, upon this subject — AUTHOR.

The azotic gas may be procured from atmospheric air, by absorbing the oxygen gas which is mixed with it by means of a solution of sulphuret of potash, or sulphuret of lime It requires twelve or fifteen days to complete this

cured by dissolving animal substances in dilute nitric acid very little heated In this operation the azote is disengaged in form of gas, which we receive under bell glasses filled with water in the pneumato-chemical apparatus We may procure this gas by deflagrating nitre with charcoal, or any other combustible substance when with charcoal, the azotic gas is mixed with carbonic acid gas, which may be absorbed by a solution of caustic alkali or by lime water, after which the azotic gas remains pure We can procure it in a fourth manner from combinations of ammonia with metallic oxides, as pointed out by M de Fourcroy the hydrogen of the ammonia combines with the oxygen of the oxide, and forms water, whilst the azote being left free escapes in form of gas

The combinations of azote were but lately discovered M Cavendish first observed it in *nitrous gas and acid*, and M *Berthollet in ammonia* and the prussic acid As no evidence of its decomposition has hitherto appeared, we are fully entitled to consider azote as a simple elementary substance

Section VII

Observations upon Hydrogen and Its Combinations with Simple Substances

Hydrogen, as its name expresses, is one of the constituent elements of water, of which it forms fifteen hundredth parts by weight, combined with eighty five hundredth parts of oxygen This substance, the properties and even existence of which was unknown till lately, is very plentifully distributed in nature and acts a very considerable part in the processes of the

dependent of combination

To procure hydrogen, or rather hydrogen gas, we have only to subject water to the action of a substance with which oxygen has greater affinity than it has to hydrogen, by this means the hydrogen is set free and by uniting with caloric, assumes the form of hydrogen gas Red hot iron is usually employed for this purpose the iron during the process, becomes oxidated, and is changed into a substance resembling the iron ore from the island of Elba In this state of oxide it is much less attractible by the magnet, and dissolves in acids without effervescence

Charcoal, in a red heat, has the same power of decomposing water, by attracting the oxygen from its combination with hydrogen In

TABLE *of the Binary Combinations of Hydrogen with Simple Substances*

Simple Substances	*Resulting Compounds* — *New Names*	*Old Names*
Caloric	Hydrogen gas	Inflammable air
Azote	Ammonia	Volatile Alkali
Oxygen	Water	Water
Sulphur	Hydruret of sulphur, or sulphuret of hydrogen	Hitherto unknown[1]
Phosphorus	Hydruret of phosphorus, or phosphuret of hydrogen	
Charcoal	Hydro-carbonous, or car bono hydrous radicals[2]	Not known till lately
Metallic substances as iron &c	Metallic hydrurets[3], as hydruret of iron &c	Hitherto unknown

[1] These combinations take place in the state of gas and form respectively sulphurated and phosphorated oxygen gas —AUTHOR

... with charcoal ... ncludes the fixed and

this process carbonic acid gas is formed and mixes with the hydrogen gas but is easily separated by means of water or alkalies, which absorb the carbonic acid and leave the hydro- [illegible]

[illegible] solved in the acid, forming a sulphate of iron or of zinc

Some very distinguished chemists consider hydrogen as the *phlogiston* of Stahl, and as that celebrated chemist admitted the existence of phlogiston in sulphur, charcoal, metals, &c, they are, of course, obliged to suppose that hydrogen exists in all these substances, though they cannot prove their supposition, even if they could, it would not avail much, since this disengagement of hydrogen is quite insufficient to explain the phenomena of calcination and combustion We must always recur to the examination of this question, "Are the heat and [illegible]

light whatever upon this question Besides, it belongs to those who make suppositions to prove them, and, doubtless, a doctrine which

TABLE *of the Binary Combinations of Sulphur with Simple Substances*

Simple Substances	*Resulting Compounds* *New Names*	*Old Names*
Caloric	Sulphuric gas	
Oxygen	Oxide of sulphur	Soft sulphur
	Sulphurous acid	Sulphureous acid
	Sulphuric acid	Vitriolic acid
Hydrogen	Sulphuret of hydrogen	Unknown combinations
Azote	azote	
Phosphorus	phosphorus	
Charcoal	charcoal	
Antimony	antimony	Crude antimony
Silver	silver	
Arsenic	arsenic	Orpiment, realgar
Bismuth	bismuth	
Cobalt	cobalt	
Copper	copper	Copper pyrites
Tin	tin	
Iron	iron	Iron pyrites
Manganese	manganese	
Mercury	mercury	Ethiops mineral, cinnabar
Molybdenum	molybdenum	
Nickel	nickel	
Gold	gold	
Platinum	platinum	
Lead	lead	Galena
Tungsten	tungsten	
Zinc	zinc	Blende
Potash	potash	Alkaline liver of sulphur with fixed vegetable alkali
Soda	soda	Alkaline liver of sulphur with fixed mineral alkali
Ammonia	ammonia	Volatile liver of sulphur, smoking liquor of Boyle
Lime	lime	Calcareous liver of sulphur
Magnesia	magnesia	Magnesian liver of sulphur
Barytes	barytes	Barytic liver of sulphur
Argill	argill	Yet unknown

without any supposition explains the phenomena as well and as naturally as theirs does by supposition has at least the advantage of greater simplicity [1]

Section VIII

Observations on Sulphur and its Combinations

Sulphur is a combustible substance having a very great tendency to combination, it is naturally in a solid state in the ordinary temperature, and requires a heat somewhat higher than boiling water to make it liquify Sulphur is formed by nature in a considerable degree of purity in the neighbourhood of volcanos we

phur, by carrying off its oxygen by means of charcoal in a red heat carbonic acid is formed and escapes in the state of gas, the sulphur remains combined with the clay, lime, &c in the state of sulphuret, which is decomposed by acids the acid unites with the earth into a neutral salt, and the sulphur is precipitated

TABLE *of the Binary Combinations of Phosphorus with the Simple Substances*

Simple Substances	*Resulting Compounds*
Caloric	Phosphoric gas
Oxygen	Oxide of phosphorus Phosphorous acid Phosphoric acid
Hydrogen	Phosphuret of hydrogen
Azote	Phosphuret of azote
Sulphur	Phosphuret of sulphur
Charcoal	Phosphuret of charcoal
Metallic substances	Phosphuret of metals[2]
Potash Soda Ammonia Lime Barytes Magnesia Argill	Phosphuret of Potash Soda &c [3]

Section IX

Observations upon Phosphorus and its Combinations

Phosphorus is a simple combustible substance, which was unknown to chemists till 1667, when it was discovered by Brandt, who kept the process secret soon after, Kunkel found out Brandt s method of preparation and made it public It has been ever since known by the name of Kunkel s phosphorus It was for a long time procured only from urine and though Homberg gave an account of the process in the *Recueil de l Académie* for 1692, all the philosophers of Europe were supplied with it from England It was first made in France in 1737 before a committee of the Academy at the Royal Garden At present it is procured in a more commodious and more economical manner from animal bones which are real calcar

ter which has been used to wash out the adher

white pellucid glass When this is powdered and mixed with one third its weight of char

by combustion or by means of nitric acid, wherefore this latter should always be employed in experiments of research

Phosphorus is found in almost all animal substances and in some plants which give a kind of animal analysis In all these it is usually combined with charcoal hydrogen and

ing contained in charcoal gives reason to sus-

pect that it is more common in the vegetable kingdom than has generally been supposed It is certain that by proper processes it may be procured from every individual of some of the families of plants As no experiment has hitherto given reason to suspect that phosphorus is a compound body, I have arranged it with the simple or elementary substances It takes fire at the temperature of 32° (104°) of the thermometer

In the business of charring wood, this is done by a less expensive process The wood is disposed in heaps and covered with earth, so as to prevent the access of any more air than is absolutely necessary for supporting the fire, which is kept up till all the water and oil is driven off, after which the fire is extinguished by shutting up all the air holes

We may analyse charcoal either by combustion in air, or rather in oxygen gas, or by means of nitric acid In either case we convert it into carbonic acid, and sometimes a little potash and some neutral salts remain This analysis has hitherto been but little attended to by chemists and we are not even certain if potash exists in charcoal before combustion or whether it be formed by means of some unknown combination during that process

TABLE *of Binary Combinations of Charcoal*

Simple Substances	*Resulting Compounds* — *New Names*	*Old Names*
Oxygen	Oxide of charcoal	Unknown
	Carbonic acid	Fixed air, chalky acid
Sulphur	Carburet of sulphur	*Unknown*
Phosphorus	*Carburet of phosphorus*	
Azote	Carburet of azote	
Hydrogen	Carbono-hydrous radical	
	Fixed and volatile oils	
Metallic substances	Carburets of metals	Of these only the carburets of iron and zinc are known and were formerly called Plumbago
Alkalies and earths	Carburet of potash, &c	Unknown

SECTION X

Observations upon Charcoal and its Combinations with Simple Substances

As charcoal has not been hitherto decomposed, it must, in the present state of our knowledge, be considered as a simple substance By modern experiments it appears to exist ready formed in vegetables, and I have already remarked that in these it is combined with hydrogen, sometimes with azote and phosphorus, forming compound radicals which may be changed into oxides or acids according to their degree of oxygenation

To obtain the charcoal contained in vegetable or animal substances, we subject them to the action of fire, at first moderate and afterwards very strong, on purpose to drive off the last portions of water, which adhere very obstinately to the charcoal For chemical purposes, this is usually done in retorts of stoneware or porcelain, into which the wood, or other matter, is introduced, and then placed in a reverberatory furnace, raised gradually to its greatest heat The heat volatilizes, or changes into gas, all the parts of the body susceptible of combining with caloric into that form, and the charcoal, being more fixed in its nature, remains in the retort combined with a little earth and some fixed salts

SECTION XI

Observations upon the Muriatic, Fluoric, and Boracic Radicals and their Combinations

As the combinations of these substances, either with each other or with the other combustible bodies, are entirely unknown, we have not attempted to form any table for their nomenclature We only know that these radicals are susceptible of oxygenation, and of forming the muriatic, fluoric, and boracic acids, and that in the acid state they enter into a number of combinations, to be afterwards detailed Chemistry has hitherto been unable to disoxygenate any of them, so as to produce them in a simple state For this purpose, some substance must be employed to which oxygen has a stronger affinity than to their radicals, either by means of single affinity or by double elective attraction All that is known relative to the origin of the radicals of these acids will be

mentioned in the sections set apart for considering their combinations with the salifiable bases

SECTION XII

Observations upon the Combinations of Metals with Each Other

Before closing our account of the simple or

table would be both exceedingly voluminous and very unsatisfactory, without going into a series of experiments not yet attempted, I have thought it adviseable to omit it altogether All that is necessary to be mentioned is that these

the predominating metal

Metallic alloys, like all other combinations, have a point of saturation It would even appear, from the experiments of M de la Briche, that they have two perfectly distinct degrees of saturation

TABLE *of the Combinations of Azote Completely Saturated with Oxygen in the State of Nitric Acid, with the Salifiable Bases, in the Order of the Affinity with the Acid*

Bases	*Names of the Resulting Neutral Salts*	
	New Names	*Old Names*
Barytes	Nitrate of barytes	Nitre with a base of heavy earth
Potash	potash	*Nitre Saltpetre* Nitre with base of potash
Soda	soda	Quadrangular nitre, Nitre with base of mineral alkali
Lime	lime	Calcareous nitre Nitre with calcareous base Mother water of nitre or saltpetre
Magnesia	magnesia	Magnesian nitre Nitre with base of magnesia
Ammonia	ammonia	Ammoniacal nitre
Argill	argill	Nitrous alum, Argillaceous nitre, Nitre with base of earth of alum
Oxide of zinc	zinc	Nitre of zinc
iron	iron	Nitre of iron Martial nitre, Nitrated iron
manganese	manganese	Nitre of manganese
cobalt	cobalt	Nitre of cobalt
nickel	nickel	Nitre of nickel
lead	lead	Saturnine nitre, Nitre of lead
tin	tin	Nitre of tin
copper	copper	Nitre of copper or of Venus
bismuth	bismuth	Nitre of bismuth
antimony	antimony	Nitre of antimony
arsenic	arsenic	*Arsenical nitre*
mercury	mercury	Mercurial nitre
silver	silver	Nitre of silver or luna, Lunar caustic
gold	gold	Nitre of gold
platinum	platinum	Nitre of platinum

Table ... ous

Names of the Bases	*Names of the Neutral Salts* *New Names*	*Notes*
Barytes	Nitrate of barytes	These salts are only known of late and have received no particular name in the old *nomenclature*
Potash	potash	
Soda	soda	
Lime	lime	
Magnesia	magnesia	
Ammonia	ammonia	
Argill	argill	
Oxide of zinc	zinc	As metals dissolve both in nitrous and nitric acids metallic salts must of consequence be formed having different degrees of oxygenation Those wherein the metal is least oxygenated must be called Nitrites when more so Nitrates but the limits of this distinction are difficultly ascertainable The older chemists were not acquainted with any of these salts
iron	iron	
manganese	manganese	
cobalt	cobalt	
nickel	nickel	
lead	lead	
tin	tin	
copper	copper	
bismuth	bismuth	
antimony	antimony	
arsenic	arsenic	
mercury	mercury	
silver	It is extremely probable that gold silver and platinum only form *nitrates* and cannot subsist in the state of *nitrites*	
gold		
platinum		

SECTION XIII

Observations upon Nitrous and Nitric Acids and their Combinations with Salifiable Bases

The nitrous and nitric acids are ...

... acid is usually combined with lime and magnesia, sometimes with potash and rarely with argill As all these salts, excepting the nitrate of potash attract the moisture of the air, and consequently would be difficultly preserved advantage is taken, in the manufactures of saltpetre and the royal refining house, of the greater affinity of the nitric acid to potash than these other bases, by which means the lime, magnesia, and argill, are precipitated, and all these nitrates are reduced to the nitrate of potash or saltpetre

Th ...

filled with water, and all its joints carefully luted The nitrous acid passes over ...

... quantity of oxygen gas escapes, owing to the greater affinity of oxygen to caloric in a high temperature than to nitrous acid, though in the usual temperature of the atmosphere this affinity is reversed It is ... the d ...

tra ...
ing ...
is ...
as ...
ash ...

of nitrous gas passes over into the recipient, and very pure concentrated nitric acid remains in the retort

We have already seen that azote is the nitric [illegible]

ate quantities of oxygen between these two extremes of oxygenation produce different species of nitrous acid, or, in other words, nitric acid less or more impregnated with nitrous gas I ascertained the above proportions by means of decomposition, and, though I cannot answer for their absolute accuracy, they cannot be far removed from truth M Cavendish, who first showed by synthetic experiments that azote is the base of nitric acid, gives the proportions of azote a little larger than I have done, but, as it is not improbable that he produced the nitrous acid and not the nitric, that circumstance explains in some degree the difference in the results of our experiments

As in all experiments of a philosophical nature the utmost possible degree of accuracy is required, we must procure the nitric acid for experimental purposes from nitre which has [illegible]

TABLE *of the Combinations of Sulphuric Acid with the Salifiable Bases, in the Order of Affinity*

Names of the Bases	*Resulting Compounds* *New Names*	*Old Names*
Barytes	Sulphate of barytes	Heavy spar, vitriol of heavy earth
Potash	potash	Vitriolated tartar, *sal de duobus, arcanum duplicatam*
Soda	soda	Glauber s salt
Lime	lime	Selenite, gypsum, calcareous vitriol
Magnesia	magnesia	Epsom salt, sedlitz salt, magnesian vitriol
Ammonia	ammonia	Glauber s secret sal ammoniac
Argill	argill	Alum
Oxide of zinc	zinc	White vitriol, goslar vitriol, white coperas, vitriol of zinc
iron	iron	Green coperas, green vitriol, martial vitriol, vitriol of iron
manganese	manganese	Vitriol of manganese
cobalt	cobalt	Vitriol of cobalt
nickel	nickel	Vitriol of nickel
lead	lead	*Vitriol of lead*
tin	tin	Vitriol of tin
copper	copper	Blue coperas, blue vitriol Roman vitriol, vitriol of copper
bismuth	bismuth	Vitriol of bismuth
antimony	antimony	Vitriol of antimony
arsenic	arsenic	Vitriol of arsenic
mercury	mercury	Vitriol of mercury
silver	silver	Vitriol of silver
gold	gold	Vitriol of gold
platinum	platinum	Vitriol of platinum

long as any precipitation takes place, the sul-

acid, by dropping in a little nitrate of silver so

acid by a gentle heat and what comes over is in the most perfect degree of purity

The nitric acid is one of the most prone to combination and is at the same time very easily decomposed Almost all the simple substances with the exception of gold, silver, and platinum, rob it less or more of its oxygen, some of them even decompose it altogether It was very anciently known, and its combinations have been more studied by chemists than those of any other acid These combinations were named *nitres* by MM Macquer and

each other

Section XIV

Observations upon Sulphuric Acid and its Combinations

For a long time this acid was procured by

entine in the fifteenth century but, in modern times it is procured more economically by the combustion of sulphur in proper vessels Both to facilitate the combustion, and to assist the oxygenation of the sulphur, a little powdered saltpetre, nitrate of potash is mixed with it, the nitre is decomposed and gives out its oxygen to the sulphur, which contributes to its

nation ceases, because the oxygen is exhausted and the air of the vessels reduced almost to

is burnt in large close-built chambers lined with lead, having a little water at the bottom

then pellucid, without any flavour and nearly double the weight of an equal bulk of water This process would be greatly facilitated and the combustion much prolonged by introducing fresh air into the chambers by means of several pairs of bellows directed towards the flame of the sulphur, and by allowing the nitrous gas to escape through long serpentine canals, in contact with water, to absorb any sulphuric or sulphurous acid gas it might contain

By one experiment, M Berthollet found that 69 parts of sulphur in combustion united with 31 parts of oxygen to form 100 parts of sulphuric acid, and, by another experiment,

by weight

Table *of the Combinations of the Sulphurous Acid with the Salifiable Bases in the Order of Affinity*

Names of the Bases	*Names of the Neutral Salts*
Barytes	Sulphite of barytes
Potash	potash
Soda	soda
Lime	lime
Magnesia	magnesia
Ammonia	ammonia
Argill	argill
Oxide of zinc	zinc
iron	iron
manganese	manganese
cobalt	cobalt
nickel	nickel
lead	lead
tin	tin
copper	copper
bismuth	bismuth
antimony	antimony
arsenic	arsenic
mercury	mercury
silver	silver
gold	gold
platinum	platinum

Author.

This acid, in common with every other, can only dissolve metals when they have been previously oxidated, but most of the metals are capable of decomposing a part of the acid, so as to carry off a sufficient quantity of oxygen to render themselves soluble in the part of the acid which remains undecomposed This hap- [illegible]

but they do not sufficiently disoxygenate the decomposed part of the acid to reconvert it into sulphur, it is only reduced to the state of sulphurous acid, which, being volatilised by the heat, flies off in form of sulphurous acid gas

Silver, mercury, and all the other metals except iron and zinc, are insoluble in diluted sulphuric acid, because they have not sufficient affinity with oxygen to draw it off from its combination either with the sulphur, the sulphurous acid, or the hydrogen, but iron and zinc, being assisted by the action of the acid, decompose the water and become oxidated at its expense, without the help of heat

SECTION XV

Observations upon Sulphurous Acid and its Combinations with Salifiable Bases

The sulphurous acid is formed by the union of oxygen with sulphur by a lesser degree of oxygenation than the sulphuric acid It is pro- [illegible]

over in the sulphurous state of oxygenation This acid, in the common pressure and temperature of the air, can only exist in form of gas, but it appears, from the experiments of M Clouet, that, *in a very low temperature*, it condenses and becomes fluid Water absorbs a great deal more of this gas than of carbonic acid gas, but much less than it does of muriatic acid gas

That the metals cannot be dissolved in acids [illegible]

TABLE *of the Combinations of Phosphorous and Phosphoric Acids, with the Salifiable Bases in Order of Affinity*

Names of the Bases	*Names of the Neutral Salts formed by Phosphorous Acid*	*Phosphoric Acid*
Lime	Phosphites of lime[2]	Phosphates of lime[3]
Barytes	barytes	barytes
Magnesia	magnesia	magnesia
Potash	potash	potash
Soda	soda	soda
Ammonia	ammonia	ammonia
Argill	argill	argill
Oxides of zinc[1]	zinc	zinc
iron	iron	iron
manganese	manganese	manganese
cobalt	cobalt	cobalt
nickel	nickel	nickel
lead	lead	lead
tin	tin	tin
copper	copper	copper
bismuth	bismuth	bismuth
antimony	antimony	antimony
arsenic	arsenic	arsenic
mercury	mercury	mercury
silver	silver	silver
gold	gold	gold
platinum	platinum	platinum

[1] The existence of metallic phosphites supposes that metals are suscep- [illegible] at different degrees of oxygenation

lished fact which I have perhaps repeated too often Hence, as sulphurous acid is already deprived of great part of the oxygen necessary for forming the sulphuric acid, it is more disposed to recover oxygen than to furnish it to the greatest part of the metals, and, for this reason, it cannot dissolve them unless previously oxidated by other means From the same principle it is that the metallic oxides dissolve without effervescence, and with great facility, in sulphurous acid This acid, like the muriatic, has even the property of dissolving metallic oxides surcharged with oxygen, and consequently insoluble in sulphuric acid, and in this way forms true sulphates Hence we might be led to conclude that there are no metallic sulphites, were it not that the phenomena which accompany the solution of iron, mercury, and some other metals, convince us that these metallic substances are susceptible of two degrees of oxidation, during their solution in acids Hence the neutral salt in which the metal is least oxidated must be named *sulphite*, and that in which it is fully oxidated must be called *sulphate* It is yet unknown whether this distinction is applicable to any of the metallic sulphates, except those of iron and mercury

SECTION XVI

Observations upon Phosphorous and Phosphoric Acids and their Combinations with Salifiable Bases

Under the article Phosphorus, Part II, Section IX, we have already given a history of the discovery of that singular substance, with some

TABLE *of the Combinations of Carbonic Acid, with the Salifiable Bases, in the Order of Affinity*

Names of Bases[1]	Resulting Neutral Salts — *New Names*	*Old Names*
Barytes	Carbonates of barytes	Aerated or effervescent heavy earth
Lime	lime	Chalk, calcareous spar, aerated calcareous earth
Potash	potash	Effervescing or aerated fixed vegetable alkali, mephitis of potash
Soda	soda	Aerated or effervescing fixed mineral alkali, mephitic soda
Magnesia	magnesia	Aerated, effervescing mild, or mephitic magnesia
Ammonia	ammonia	Aerated, effervescing, mild, or mephitic volatile alkali
Argill	argill	Aerated or effervescing argillaceous earth or earth of alum
Oxide of zinc	zinc	Zinc spar, mephitic or aerated zinc
iron	iron	Sparry iron-ore, mephitic or aerated iron
manganese	manganese	Aerated manganese
cobalt	cobalt	Aerated cobalt
nickel	nickel	Aerated nickel
lead	lead	Sparry lead-ore, or aerated lead
tin	tin	Aerated tin
copper	copper	Aerated copper
bismuth	bismuth	Aerated bismuth
antimony	antimony	Aerated antimony
arsenic	arsenic	Aerated arsenic
mercury	mercury	Aerated mercury
silver	silver	Aerated silver
gold	gold	Aerated gold
platinum	platinum	Aerated platinum

[1] As these salts have only been understood of late they have not properly speaking any old names M Morveau in the First volume of the *Encyclopedia* calls them *Mephites* M Bergman gives them the name of *aerated*, and M de Fourcroy, who calls the carbonic acid *chalky acid* gives them the name of *chalks* —AUTHOR.

observations upon the mode of its existence in [illegible]

water during combustion it absorbs twice and a half its weight of oxygen so that 100 parts of phosphoric acid is composed of 28½ parts of phosphorus united to 71½ parts of oxygen. *This acid may be obtained concrete, in form of* white flakes which greedily attract the moisture of the air, by burning phosphorus in a dry glass over mercury

To obtain phosphorous acid which is phosphorus less oxygenated than in the state of phosphoric acid, the phosphorus must be burnt by a very slow spontaneous combustion over a glass funnel leading into a crystal phial after a few days, the phosphorus is found oxygenated, and the phosphorous acid in proportion as it forms has attracted moisture from the air and dropped into the phial The phosphorous acid is readily changed into phosphoric acid by exposure for a long time to the free air *it absorbs oxygen from the air and becomes* fully oxygenated

As phosphorus has a sufficient affinity for oxygen to attract it from the nitric and muriatic acids, we may form phosphoric acid by means of these acids in a very simple and cheap manner Fill a tubulated receiver half full of concentrated nitric acid and heat it gently then throw in small pieces of phosphorus [illegible]

drive off the last particles of nitric acid phosphoric acid, partly fluid and partly concrete, remains in the retort

Section XVII

Observations upon Carbonic Acid and its Combinations with Salifiable Bases

Of all the known acids the carbonic is the most abundant in nature it exists ready formed [illegible] incapable of being condensed into the solid or liquid form by any degree of cold or of pressure hitherto known, unites to about its own bulk of water and thereby forms a very weak acid It may likewise be obtained in great abundance from saccharine matter in fermentation but is then contaminated by a small portion of alcohol which it holds in solution

As charcoal is the radical of this acid, we may form it *artificially by burning* charcoal in oxygen gas, or by combining charcoal and metallic oxides in proper proportions the oxygen of the oxide combines with the charcoal, forming carbonic acid gas, and the metal being left free recovers its metallic or reguline form

We are indebted for our first knowledge of this acid to Dr Black, before whose time its property of remaining always in the state of gas had made it to elude the researches of chemistry

It would be a most valuable discovery to society if we could decompose this gas by any cheap process as by that means we might obtain, *for economical purposes, the immense* store of charcoal contained in calcareous earths, marbles, limestones, &c This cannot be effected by single affinity, because to decompose the carbonic acid it requires a substance as

TABLE *of the Combinations of Oxygenated Muriatic Acid with the Salifiable Bases, in the Order of Affinity*

Names of the Bases	*Neutral Salts*	*New Names*
Barytes	Oxygenated muriate of	barytes
Potash		potash
Soda		soda
Lime		lime
Magnesia		magnesia
Argill		argill
Oxide of zinc		zinc
iron		iron
manganese		manganese
cobalt		cobalt
nickel		nickel
lead		lead
tin		tin
copper		copper
bismuth		bismuth
antimony		antimony
arsenic		arsenic
mercury		mercury
silver		silver
gold		gold
platinum		platinum

This order of salts entirely unknown to the ancient chemists was discovered in 1786 by M Berthollet.—AUTHOR

TABLE *of the Combinations of Muriatic Acid with the Salifiable Bases in the Order of Affinity*

Names of the Bases	*Resulting Neutral Salts* *New Names*	*Old Names*
Barytes	Muriate of barytes	Sea salt, having base of heavy earth
Potash	potash	Febrifuge salt of Sylvius, Muriated vegetable fixed alkali
Soda	soda	Sea salt
Lime	lime	Muriated lime Oil of lime
Magnesia	magnesia	Marine Epsom salt Muriated magnesia
Ammonia	ammonia	Sal ammoniac
Argill	argill	Muriated alum sea-salt with base of earth of alum
Oxide of zinc	zinc	Sea-salt of or muriatic zinc
iron	iron	Salt of iron Martial sea-salt
manganese	manganese	Sea-salt of manganese
cobalt	cobalt	Sea-salt of cobalt
nickel	nickel	Sea salt of nickel
lead	lead	Horny-lead, *plumbum corneum*
tin	smoking of tin solid of tin	Smoking liquor of Libavius Solid butter of tin
copper	copper	Sea-salt of copper
bismuth	bismuth	Sea-salt of bismuth
antimony	antimony	Sea-salt of antimony
arsenic	arsenic	Sea-salt of arsenic
mercury	sweet of mercury corrosive of mercury	Sweet sublimate of mercury, calomel *aquila alba* Corrosive sublimate of mercury
silver	silver	Horny silver *argentum corneum luna cornea*
gold	gold	Sea-salt of gold
platinum	platinum	Sea-salt of platinum

nature during vegetation from the most common materials

SECTION XVIII

Observations upon Muriatic and Oxygenated Muriatic Acid and their Combinations with Salifiable Bases

Muriatic acid is very abundant in the mineral kingdom naturally combined with different salifiable bases, especially with soda, lime, and magnesia In sea water, and the water of several lakes it is combined with these three bases and in mines of rock salt it is chiefly united to soda This acid does not appear to have been hitherto decomposed in any chemical experiment so that we have no idea what ever of the nature of its radical and only con [illegible]

The muriatic acid has only a moderate adherence to the salifiable bases and can readily

be driven from its combination with these by sulphuric acid Other acids, as the nitric for instance, may answer the same purpose, but nitric acid being volatile would mix, during *distillation, with the muriatic About one part* of sulphuric acid is sufficient to decompose two parts of decrepitated sea salt This operation is performed in a tubulated retort, having Woulfe's apparatus, (Plate IV, *Fig 1*), adapted to it When all the junctures are properly luted, the sea salt is put into the retort through the tube, the sulphuric acid is poured on, and the opening immediately closed with its ground crystal stopper As the muriatic acid can only subsist in the gaseous form in the ordinary temperature, we could not condense it without the presence of water Hence the use of the water with which the bottles in Woulfe's apparatus are half filled, the muriatic acid gas, driven off from the sea salt in the retort, combines with the water and forms what the old chemists called *smoking spirit of salt*, or *Glauber's spirit of sea salt*, which we now name *muriatic acid*

TABLE *of the Combinations of Nitro-Muriatic Acid with the Salifiable Bases in the Order of Affinity so Far as is Known*

Names of the Bases	*Names of the Neutral Salts*
Argill	Nitro muriate of argill
Ammonia	ammonia
Oxide of antimony	antimony
silver	silver
arsenic	arsenic
Barytes	barytes
Oxide of bismuth	bismuth
Lime	lime
Oxide of cobalt	cobalt
copper	copper
tin	tin
iron	iron
Magnesia	magnesia
Oxide of manganese	manganese
mercury	mercury
molybdenum	*molybdenum*
nickel	nickel
gold	gold
platinum	platinum
lead	lead
Potash	potash
Soda	soda
Oxide of tungsten	tungsten
zinc	zinc

Note—Most of these combinations especially those with the earths and alkalies have been little examined and we are yet to learn whether they form a mixed salt in which the compound radical remains combined or if the two acids separate to form two distinct neutral salts—AUTHOR

The acid obtained by the above process is

tity by water When the impregnation of water with this gas is pushed beyond a certain point, the superabundant acid precipitates to the bottom of the vessels in a concrete form M Berthollet has shown that this acid is capable of combining with a great number of the salifiable bases, the neutral salts which result from this union are susceptible of deflagrating with charcoal and many of the metallic substances, these deflagrations are very violent and dangerous, owing to the great quantity of caloric which the oxygen carries alongst with it into the composition of oxygenated muriatic acid

SECTION XIX

Observations upon Nitro-Muriatic Acid and its Combinations with Salifiable Bases

The nitro muriatic acid, formerly called *aqua regia*, is formed by a mixture of nitric and muriatic acids, the radicals of these two acids

gage nitrous gas by heating this acid ...

... compound base or radical

Table of the Combinations of Fluoric Acid with the Salifiable Bases, in the Order of Affinity

Names of the Bases	*Names of the Neutral Salts*
Lime	Fluat of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
arsenic	arsenic
bismuth	bismuth
mercury	mercury
silver	silver
gold	gold
platinum	platinum
And by the dry way,	
Argill	Fluat of argill

Note —These combinations were entirely unknown to the old chemists and consequently have no names in the old nomenclature —Author.

Section XX

Observations upon the Fluoric Acid and its Combinations with Salifiable Bases

... is applied to the retort The sulphuric acid, from its greater affinity, expels the fluoric acid which passes over and ...

silicious earth and even renders these ... volatile, carrying them over with itself ... tillation in the gaseous form

We are indebted to M ...

... much increased our kn... edge of ...

... in any experiment It ... only by means of compound affinity that e... periments can be made with this view with ... probability of success

Bases	*Neutral Salts*
Lime	Borate of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Oxide of zinc	zinc
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
mercury	mercury
Argill	argill

Note —Most of these combinat... known ...

Section XXI

Observations upon Boracic Acid and its Combinations with Salifiable Bases

This ...

hands of the Dutch, who have been exclusively possessed of the art of purifying it till very lately when MM L'Eguillier of Paris have rivalled them in the manufacture, but the process still remains a secret to the world

By chemical analysis we learn that borax is a neutral salt with excess of base, consisting of soda, partly saturated with a peculiar acid long called *Homberg's sedative salt*, now *the boracic acid* This acid is found in an uncombined state in the waters of certain lakes That of Cherchiaio in Italy contains 94½ grains in each pint of water

To obtain boracic acid, dissolve some borax in boiling water, filtrate the solution, and add sulphuric acid, or any other having greater affinity to soda than the boracic acid this latter acid is separated and is procured in a crystalline form by cooling This acid was long considered as being formed during the process by which it is obtained and was consequently supposed to differ according to the nature of the acid employed in separating it from the soda, but it is now universally acknowledged that it is identically the same acid, in whatever way procured, provided it be properly purified from mixture of other acids by washing and by repeated solution and crystallization It is soluble both in water and alcohol and has the property of communicating a green colour to the flame of that spirit This circumstance led to a suspicion of its containing copper, which is not confirmed by any decisive experiment On the contrary, if it contain any of that metal, it must only be considered as an accidental mixture It combines with the salifiable bases in [illegible]

The table presents its combinations in the [illegible]

after soda

The boracic radical is hitherto unknown, no [illegible]

TABLE *of the Combinations of Arseniac Acid with the Salifiable Bases, in the Order of Affinity*

Bases	*Neutral Salts*
Lime	Arseniate of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
bismuth	bismuth
mercury	mercury
antimony	antimony
silver	silver
gold	gold
platinum	platinum
Argill	argill

Note —This order of salts was entirely unknown to the ancient chemists M Macquer in 1746 discovered the combinations of arseniac acid with potash and soda to which he gave the name of *arsenical neutral salts* —AUTHOR.

SECTION XXII

Observations upon Arseniac Acid and its Combinations with Salifiable Bases

In the *Recueil de l'Académie* for 1746, M [illegible]

in which a metal acts the part of an acid, was [illegible]

[illegible]bination The most simple and most [illegible] of these is as follows dissolve white oxide of [illegible] three parts, by weight, of muriatic

entirely freed from the other acids employed during the process by heating it in a crucible till it begins to grow red, what remains is pure concrete arseniac acid

M Scheele s process which was repeated with great success by M Morveau in the laboratory at Dijon is as follows distil muriatic acid from the black oxide of manganese this *converts it into oxygenated* muriatic acid by carrying off the oxygen from the manganese receive this in a recipient containing white oxide of arsenic covered by a little distilled water the arsenic decomposes the oxygenated muriatic acid by carrying off its supersaturation of oxygen the arsenic is converted into arseniac acid *and the oxygenated* muriatic *acid* is brought back to the state of common muriatic acid The two acids are separated by distillation with a gentle heat increased towards the end of the operation the muriatic acid passes over and the arseniac *acid remains* behind in a white concrete form

The arseniac acid is considerably less volatile than white oxide of arsenic it often contains white oxide of arsenic in solution owing to its not being sufficiently oxygenated this is prevented by *continuing* to add nitrous acid as in the former process till no more nitrous gas is produced From all these observations I *would* give the follow [illegible] acid [1] [illegible] by [illegible] oxygen fire [illegible] soluble in water and capable of combining with many of the salifiable bases

Section XXIII

Observations upon Molybdic Acid and its Combinations with Salifiable Bases

Molybdenum is a particular metallic body, capable of *being oxygenated* so far as to become a true concrete acid [1] For this purpose one part ore of *molybdenum* which is a natural *sulphuret of that metal is put into a retort* with five or six parts nitric acid, diluted with a *quarter of its* weight of water, and heat is applied to the retort the oxygen of the nitric acid acts both upon *the molybdenum* and the *sul*phur, converting the one into molybdic and the other into sulphuric acid, pour on fresh quantities of nitric acid so long as any red fumes of nitrous gas escape the molybdenum is then oxygenated as far as is poss [illegible] *found at the* bott [illegible] lent form [illegible] in warm [illegible] cles of su [illegible] and as it [illegible] uble we kno [illegible] All its com [illegible] unknown t [illegible] chemists

[1] This acid was discovered by M Scheele to whom chemistry is indebted for the discovery of several other acids —AUTHOR.

TABLE of the Combinations of Tungstic Acid with the Salifiable Bases

Bases	*Neutral Salts*
Lime	Tungstate of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Argill	argill
Oxide of antimony &c	antimony &c [1]

Section XXIV

Observations upon Tungstic Acid and its Combinations with Salifiable Bases

Tungsten is a particular metal the ore of which has frequently been confounded with that of tin The specific gravity of this ore is to water as 6 to 1 *in its form of crystallization it* resembles the garnet and varies in colour from a pearl white to yellow and reddish it is found in several parts of Saxony and Bohemia The *mineral* called *wolfram* which is frequent in the mines of Cornwall is likewise an ore of this metal In all these ores the metal is oxidated and in some of them, it appears even to be oxygenated to the state of acid, being *combined with lime into a true tungstate of* lime

To obtain the acid free mix one part of ore of tungsten with four parts of carbonate of potash and *melt* the mixture in a crucible then *powder and pour on twelve parts of boiling wa*ter add nitric acid and the tungstic acid precipitates *in a concrete* form Afterwards, to insure the complete oxygenation of the metal, *add more nitric acid* and evaporate *to dryness* repeating this operation so long as red fumes of nitrous gas are *produced* To procure tungstic acid perfectly pure the fusion of the ore with carbonate of potash must be made in a crucible of platinum otherwise the earth of the com

[1] All these salts were unknown to the ancient chemists —AUTHOR

mon crucibles will mix with the products and adulterate the acid

TABLE *of the Combinations of Tartarous Acid with the Salifiable Bases, in the Order of Affinity*

Bases	*Neutral Salts*
Lime	Tartarite of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Argill	argill
Oxide of zinc	zinc
iron	iron
manganese	manganese
cobalt	cobalt
nickel	nickel
lead	lead
tin	tin
copper	copper
bismuth	bismuth
antimony	antimony
arsenic	arsenic
silver	silver
mercury	mercury
gold	gold
platinum	platinum

SECTION XXV

Observations upon Tartarous Acid and its Combinations with Salifiable Bases

Tartar, or the concretion which fixes to the inside of vessels in which the fermentation of wine is completed, is a well known salt, composed of a peculiar acid united in considerable excess to potash M Scheele first pointed out the method of obtaining this acid pure Having

tartarite of lime which is formed, being almost insoluble in cold water, falls to the bottom and is separated from the solution of potash by de-

left free A small quantity of gas, not yet examined, is disengaged during this process At

the end of twelve hours having decanted off the clear liquor, wash the sulphate of lime in cold water, which add to the decanted liquor, then evaporate the whole, and the tartarous acid is obtained in a concrete form Two pounds

As the combustible radical exists in excess, or as the acid from tartar is not fully saturated with oxygen we call it *tartarous acid*, and the neutral salts formed by its combinations with salifiable bases *tartarites* The base of the tartarous acid is a carbono hydrous or hydro-carbonous radical, less oxygenated than in the oxalic acid, and it would appear, from the experiments of M Hassenfratz, that azote enters into the composition of the tartarous radical even in considerable quantity By oxygenating the tartarous acid, it is convertible into oxalic, malic, and acetous acids but it is probable the proportions of hydrogen and charcoal in the radical are changed during these conversions, and that the difference between these acids does not alone consist in the different degrees

tartar, which in our new nomenclature is named *acidulous tartarite of potash* by a second or equal degree of saturation a perfectly neutral salt is formed, formerly called *vegetable salt*, which we name *tartarite of potash* With soda this acid forms tartarite of soda formerly called *sal de Seignette*, or *sal polychrest of Rochell*

SECTION XXVI

Observations upon Malic Acid and its Combinations with Salifiable Bases

The malic acid exists ready formed in the

unites with the lead into an insoluble sulphate and the malic acid remains free in the liquor

This acid, which is found mixed with citric and tartarous acid in a great number of fruits is a kind of medium between oxalic and acetous acids, being more oxygenated than the former and less so than the latter From this circumstance, M Hermbstadt calls it *imperfect vinegar*, but it differs likewise from acetous acid, by having rather more charcoal and less hydrogen in the composition of its radical

When an acid much diluted has been used in the foregoing process the liquor contains oxalic as well as malic acid and probably a little tartarous, these are separated by mixing limewater with the acids, oxalate tartarite, and malate of lime are produced the two former,

TABLE *of the Combinations of Citric Acid with the Salifiable Bases in the Order of Affinity*[1]

Bases	*Neutral Salts*
Barytes	Citrate of barytes
Lime	lime
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
cobalt	cobalt
copper	copper
arsenic	arsenic
mercury	mercury
antimony	antimony
silver	silver
gold	gold
platinum	platinum
Argill	argill

being insoluble, are precipitated, and the malate of lime remains dissolved from this the pure malic acid is separated by the acetite of lead and afterwards by sulphuric acid as directed above

SECTION XXVII

Observations upon Citric Acid and its Combinations with Salifiable Bases

The citric acid is procured by expression from lemons and is found in the juices of many other fruits mixed with malic acid To obtain it pure and concentrated, it is first allowed to depurate from the mucous part of the fruit by long rest in a cool cellar, and is afterwards concentrated by exposing it to the temperature of 4 or 5 degrees below zero, from 21° to 23° of Fahrenheit; the water is frozen, and the acid remains liquid, reduced to about an eighth part of its original bulk A lower degree of cold would occasion the acid to be engaged amongst the ice, and render it difficultly separable This process was pointed out by M Georgius

It is more easily obtained by saturating the lemon juice with lime, so as to form a citrate of lime which is insoluble in water, wash this salt and pour on a proper quantity of sulphuric acid this forms a sulphate of lime, which precipitates and leaves the citric acid free in the liquor

TABLE *of the Combinations of Pyro-lignous Acid with the Salifiable Bases, in the Order of Affinity*[2]

Bases	*Neutral Salts*
Lime	Pyro-mucite of lime
Barytes	barytes
Potash	potash
Soda	soda
Magnesia	magnesia
Ammonia	ammonia
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
arsenic	arsenic
bismuth	bismuth
mercury	mercury
antimony	antimony
silver	silver
gold	gold
platinum	platinum
Argill	argill

SECTION XXVIII

Observations upon Pyro-lignous Acid and its Combinations with Salifiable Bases

The ancient chemists observed that most of the woods, especially the more heavy and compact ones, gave out a particular acid spirit, by distillation, in a naked fire, but, before M

[1] These combinations were unknown to the ancient chemists The order of affinity of the salifiable bases with this acid was determined by M Bergman and by M de Breney of the Dijon Academy —AUTHOR.

[2] The above affinities were determined by MM de Morveau and Eloi Bourfier de Clervaux These combinations were entirely unknown till lately.—AUTHOR.

Goethng, who gives an account of his experiments upon this subject in Crell's *Chemical Journal* for 1779, no one had ever made any inquiry into its nature and properties This acid appears to be the same, whatever be the wood it is procured from When first distilled, it is of a brown colour and considerably im-

and charcoal

SECTION XXIX

Observations upon Pyro-tartarous Acid and its Combinations with Salifiable Bases

The name of *Pyro-tartarous acid* is given to a dilute empyreumatic acid obtained from purified acidulous tartarite of potash by distillation in a naked fire To obtain it, let a retort be half filled with powdered tartar, adapt a tubu-

a funnel A vast quantity of carbonic acid gas is disengaged during the distillation The acid obtained by the above process is much contaminated with oil, which ought to be separated from it Some authors advise to do this by a second distillation, but the Dijon academicians inform us that this is attended with great dan-

TABLE *of the Combinations of Pyro mucous Acid, with the Salifiable Bases, in the Order of Affinity*[1]

Bases	*Neutral Salts*
Potash	Pyro mucite of potash
Soda	soda
Barytes	barytes
Lime	lime
Magnesia	magnesia
Ammonia	ammonia
Argill	argill
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
arsenic	arsenic
bismuth	bismuth
antimony	antimony

[1] All these combinations were unknown to the ancient chemists —AUTHOR

ger from explosions which take place during the process

SECTION XXX

Observations upon Pyro mucous Acid and its Combinations with Salifiable Bases

This acid is obtained by distillation in a na

verging to red, and leaves a mark upon the skin which will not remove but alongst with the epidermis It may be procured less coloured, by means of a second distillation, and is concentrated by freezing, as is directed for the citric acid It is chiefly composed of water and oil slightly oxygenated and is convertible into oxalic and malic acids by farther oxygenation with the nitric acid

It has been pretended that a large quantity of gas is disengaged during the distillation of this acid, which is not the case if it be conducted slowly by means of moderate heat

SECTION XXXI

Observations upon Oxalic Acid and its Combinations with Salifiable Bases

The oxalic acid is mostly prepared in Switzerland and Germany from the expressed juice

TABLE *of the Combinations of the Oxalic Acid, with the Salifiable Bases in the Order of Affinity*[1]

Bases	*Neutral Salts*
Lime	Oxalate of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Argill	argill
Oxide of zinc	zinc
iron	iron
manganese	manganese
cobalt	cobalt
nickel	nickel
lead	lead
copper	copper
bismuth	bismuth
antimony	antimony
arsenic	arsenic
mercury	mercury
silver	silver
gold	gold
platinum	platinum

[1] All unknown to the ancient chemists —AUTHOR

of sorrel, from which it crystallizes by being left long at rest, in this state it is partly saturated with potash [illegible] oxalate[illegible] obtain it [illegible] oxygena[illegible] oxalic ra[illegible] or eight [illegible] heat, a c[illegible] and a gr[illegible] nitrous gas is disengaged, the nitric acid is decomposed, and its oxygen unites to the sugar By allowing the liquor to stand at rest, crystals of pure oxalic acid are formed, which must be dried upon blotting paper to separate any remaining portions of nitric acid, and, to ensure the purity of the acid, dissolve the crystals in distilled water and crystallize them afresh

From the liquor remain[illegible] [illegible] tity [illegible]

TABLE of the Combinations of Acetous Acid with the Salifiable Bases in the Order of Affinity

Bases	*Neutral Salts*	*Names of the Resulting Neutral Salts According to the Old Names*
Barytes	Acetite of barytes	Unknown to the ancients Discovered by M de Morveau who calls it *barotic acéte*
Potash	potash	*Secret terra foliata tartari* of Muller *Arcanum tartari* of Basil Valentin and Paracelsus *Purgative magistery of tartar* of Schroëder *Essential salt of wine* of Zwelfer *Regenerated tartar* of Tachenius *Diuretic salt* of Sylvius and Wilson
Soda	soda	Foliated earth with base of mineral alkali Mineral or crystallizable foliated earth Mineral acetous salt
Lime	lime	Salt of chalk coral or crabs eyes mentioned by Hartman
Magnesia	magnesia	First mentioned by M Wenzel
Ammonia	ammonia	*Spiritus Mindereri* Ammoniacal acetous salt
Oxide of zinc	zinc	Known to Glauber Schwedemberg, Respour Pott de Lassone and Wenzel but not named
manganese	manganese	Unknown to the ancients
iron	iron	Martial vinegar Desc[illegible] en-[illegible]
lead	lead	[illegible]
tin	tin	[illegible] es-[illegible]
cobalt	cobalt	[illegible]
copper	copper	[illegible] gris crystals of verditer verditer distilled verd gris crystals of Venus or of copper
nickel	nickel	Unknown to the ancients
arsenic	arsenic	Arsenico-acetous fuming liquor *liquid phosphorus* of M Cadet
bismuth	Acetite of bismuth	*Sugar of bismuth* of M Geoffroy Known to Gellert, Pott Weslendorf Bergman and de Morveau
mercury	mercury	Mercurial foliated earth Keyser's famous antivenereal remedy Mentioned by Gebaver in 1748 known to Helot Margraff Baumé, Bergman and de Morveau
antimony	antimony	Unknown
silver	silver	Described by Margraff Monnet, and Wenzel unknown to the *ancients*
gold	gold	Little known mentioned by Schroëder and Juncker
platinum	platinum	Unknown
Argill	argill	According to M Wenzel vinegar dissolves only a very small proportion of argill

tion These combinations form triple salts, or neutral salts with double bases, which ought to have proper names The salt of sorrel, which is potash having oxalic acid combined in excess, is named acidulous oxalate of potash in our new nomenclature

The acid procured from sorrel has been known to chemists for more than a century, being mentioned by M Duclos in the *Recueil de l Académie* for 1688, and was pretty accurately described by Boerhaave, but M Scheele first showed that it contained potash and demonstrated its identity with the acid formed by the oxygenation of sugar

SECTION XXXII

Observations upon Acetous Acid and its Combinations with Salifiable Bases

This acid is composed of charcoal and hydro-

but the elements exist in different proportions in each of these, and it would appear that the acetous acid is in a higher state of oxygenation than these other acids I have some reason to believe that the acetous radical contains a

separated from other vinegar during fermentation, or some similar matter The spiritous part of the wine, which consists of charcoal and hydrogen, is oxygenated and converted into vinegar This operation can only take place with free access of air and is always attended by a diminution of the air employed in conse-

changed by the process, and is not exactly of the same nature with what remains in the alembic, but seems less oxygenated This circumstance has not been formerly observed by chemists.

Distillation is not sufficient for depriving this acid of all its unnecessary water, and, for this purpose, the best way is by exposing it to a degree of cold from 4° to 6° below the freezing point, from 19° to 23° of Fahrenheit by this means the aqueous part becomes frozen and leaves the acid in a liquid state and considerably concentrated In the usual temperature of the air, this acid can only exist in the gaseous form and can only be retained by combination with a large proportion of water There are other chemical processes for obtaining the acetous acid, which consi t in oxygenating the tartarous, oxalic, or malic acids, by means of nitric acid, but there is reason to believe the proportions of the elements of the radical are changed during this process M Hassenfratz is at present engaged in repeating the experiments by which these conversions are said to be produced

The combinations of acetous acid with the various salifiable bases are very readily formed, but most of the resulting neutral salts are not crystallizable, whereas those produced by the tartarous and oxalic acids are, in general, hardly soluble Tartarite and oxalate of lime are not soluble in any sensible degree The malates are a medium between the oxalates and ace-

TABLE *of the Combinations of Acetic Acid with the Salifiable Bases in the Order of Affinity*

Bases	*Neutral Salts*
Barytes	Acetate of barytes
Potash	potash
Soda	soda
Lime	lime
Magnesia	magnesia
Ammonia	ammonia
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
arsenic	arsenic
bismuth	bismuth
mercury	mercury
antimony	antimony
silver	silver
gold	gold
platinum	platinum
Argill	argill

Note —All these salts were unknown to the an cients and even those chemists who are most versant *in modern discoveries*, are yet at a loss whether the greater part of the salts produced by the oxygenated acetic rad cal belong properly to the class of acetites or to that of acetates.—AUTHOR

tites, with respect to solubility, and the malic acid is in the middle degree of saturation between the oxalic and acetous acids With this, as with all the acids, the metals require to be oxidated previous to solution

The ancient chemists knew hardly any of the salts formed by the combinations of acetous acid with the salifiable bases, except the acetites of potash, soda, ammonia, copper, and lead M Cadet discovered the acetite of arsenic,[1] M Wenzel, the Dijon academicians, M de Lassone, and M Proust, made us acquainted with the properties of the other acetites From the property which acetite of potash possesses, of giving out ammonia in distillation, there is some reason to suppose that, besides charcoal and hydrogen, the acetous radical contains a small proportion of azote, though it is not impossible but the above production of ammonia may be occasioned by the decomposition of the potash

Section XXXIII

Observations upon Acetic Acid and its Combinations with Salifiable Bases

We have given to radical vinegar the name of acetic acid, from supposing that it consists of the same radical with that of the acetous acid but more highly saturated with oxygen According to this idea, acetic acid is the highest degree of oxygenation of which the hydro-carbonous radical is susceptible, but, although this circumstance be extremely probable, it requires to be confirmed by further and more decisive experiments, before it be adopted as an absolute chemical truth We procure this acid as follows upon three parts acetite of potash or of copper pour one part of concentrated sulphuric acid, and, by distillation, a very highly concentrated vinegar is obtained, which we call *acetic acid*, formerly named *radical vinegar* It is not rigorously proved that this acid is more highly oxygenated than the acetous acid, nor that the difference between them may not consist in a different proportion between the elements of the radical or base

Section XXXIV

Observations upon Succinic Acid and its Combinations with Salifiable Bases

The succinic acid is drawn from amber by sublimation in a gentle heat and rises in a concrete form into the neck of the subliming vessel The operation must not be pushed too far, or by too strong a fire, otherwise the oil of the amber rises alongst with the acid The salt is dried upon blotting paper and purified by repeated solution and crystallization

This acid is soluble in twenty-four times its weight of cold water and in a much smaller quantity of hot water It possesses the qualities of an acid in a very small degree and only affects the blue vegetable colours very slightly The affinities of this acid, with the salifiable bases, are taken from M de Morveau, who is the first chemist that has endeavoured to ascertain them

Table *of the Combinations of Succinic Acid with the Salifiable Bases, in the Order of Affinity*

Bases	*Neutral Salts*
Barytes	Succinate of barytes
Lime	lime
Potash	potash
Soda	soda
Ammonia	ammonia
Magnesia	magnesia
Argill	argill
Oxide of zinc	zinc
iron	iron
manganese	manganese
cobalt	cobalt
nickel	nickel
lead	lead
tin	tin
copper	copper
bismuth	bismuth
antimony	antimony
arsenic	arsenic
mercury	mercury
silver	silver
gold	gold
platinum	platinum

Note—All the succinates were unknown to the ancient chemists —Author

[1] *Savans Etrangers* Vol III

Section XXXV

Observations upon Benzoic Acid and its Combinations with Salifiable Bases

This acid was known to the ancient chemists under the name of *Flowers of Benjamin, or of Benzoin*, and was procured, by sublimation, from the gum or resin called *Benzoin* The means of procuring it, *via humida*, was discovered by M Geoffroy and perfected by M Scheele Upon benzoin, reduced to powder, pour strong lime-water, having rather an excess of lime, keep the mixture continually stirring

and, after half an hour's digestion, pour off the liquor and use fresh portions of lime-water in the same manner, so long as there is any appearance of neutralization Join all the decanted liquors and evaporate, as far as possible, without occasioning crystallization, and, when the liquor is cold, drop in muriatic acid till no more precipitate is formed By the former part of the process a benzoate of lime is formed, and by the latter the muriatic acid combines with the lime, forming muriate of lime, which remains dissolved, while the benzoic acid, being insoluble, precipitates in a concrete state

Section XXXVI

Observations upon Camphoric Acid and its Combinations with Salifiable Bases

[illegible]

circumstances, we have thought necessary to give it a particular name till its nature be more completely ascertained by farther experiment

As camphor is a carbono hydrous or hydro carbonous radical it is easily conceived that, by oxygenation, it should form oxalic, malic, and several other vegetable acids This conjecture is rendered not improbable by the experiments of M Kosegarten and the principal phenomena exhibited in the combinations of camphoric acid with the salifiable bases, being very similar to those of the oxalic and malic acids, lead me to believe that it consists of a mixture of these two acids

Section XXXVII

Observations upon Gallic Acid, and its Combinations with Salifiable Bases[1]

The gallic acid, formerly called *principle of* [illegible]

Its acid properties are very weak, it reddens the tincture of turnsole, decomposes sulphurets, and unites to all the metals when they have been previously dissolved in some other acid Iron, by this combination, is precipitated of a very deep blue or violet colour The radical of this acid if it deserves the name of one, is hitherto entirely unknown, it is contained in oak willow, marsh iris, the strawberry, nymphea, Peruvian bark the flowers and bark of pomegranate and in many other woods and barks

Section XXXVIII

Observations upon Lactic Acid and its Combinations with Salifiable Bases[2]

The only accurate knowledge we have of this acid is from the works of M Scheele It is contained in whey, united to a small quantity of earth, and is obtained as follows reduce whey to one eighth part of its bulk by evaporation and filtrate, to separate all its cheesy [illegible]

Table *of the Combinations of Saccho-lactic Acid with the Salifiable Bases in the Order of Affinity*

Bases	*Neutral Salts*
Lime	Saccholate of lime
Barytes	barytes
Magnesia	magnesia
Potash	potash
Soda	soda
Ammonia	ammonia
Argill	argill
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
arsenic	arsenic
bismuth	bismuth
mercury	mercury
antimony	antimony
silver	silver

Note—All these were unknown to the ancient chemists —Author.

[1] These combinations which are called *gallates* were all unknown to the ancients and the order of their affinity is not established —Author.

[2] These combinations are called *lactates* they were all unknown to the ancient chemists and their affinities have not yet been ascertained —Author.

decantation, evaporate the remaining liquor to the consistence of honey, the lactic acid is dissolved by alcohol, which does not unite with the sugar of milk and other foreign matters these are separated by filtration from the alcohol and acid and the alcohol being evaporated, or distilled off, leaves the lactic acid behind

This acid unites with all the salifiable bases, forming salts which do not crystallize, and it seems considerably to resemble the acetous acid.

Section XXXIX

Observations upon Saccho-lactic Acid and its Combinations with Salifiable Bases

A species of sugar may be extracted, by evaporation, from whey, which has long been known in pharmacy, and which has a considerable resemblance to that procured from sugar canes This saccharine matter, like ordinary sugar, may be oxygenated by means of nitric acid For this purpose, several portions of nitric acid are distilled from it, the remaining liquid is evaporated and set to crystallize, by which means crystals of oxalic acid are procured at the same time a very fine white powder precipitates, which is the saccholactic acid discovered by Scheele It is susceptible of combining with the alkalies, ammonia, the earths and even with the metals Its action upon the latter is hitherto but little known, except that, with them, it forms difficultly soluble salts The order of affinity in the table is taken from Bergman

Table *of Combinations of Formic Acid with the Salifiable Bases, in the Order of Affinity*

Bases	*Neutral Salts*
Barytes	Formiate of barytes
Potash	potash
Soda	soda
Lime	lime
Magnesia	magnesia
Ammonia	ammonia
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
bismuth	bismuth
silver	silver
Argill	argill

Note — All unknown to the ancient chemists — Author.

Section XL

Observations upon Formic Acid and its Combinations with Salifiable Bases

This acid was first obtained by distillation from ants in the last century, by Samuel Fisher The subject was treated of by Margraff in 1749 and by MM Ardwisson and Ochrn of Leipzig in 1777 The formic acid is drawn from a large species of red ants, *formica rufa, Lin*, which form large ant hills in woody places It is procured either by distilling the ants with a gentle heat in a glass retort or an alembic, or, after having washed the ants in cold water and dried them upon a cloth, by pouring on boiling water, which dissolves the acid or the acid may be procured by gentle expression from the insects in which case it is stronger than in any of the former ways To obtain it pure, we must rectify, by means of distillation, which separates it from the uncombined oily and charry matter, and it may be concentrated by freezing, in the manner recommended for treating the acetous acid

Section XLI

Observations upon Bombic Acid and its Combinations with Salifiable Bases[1]

The juices of the silk worm seem to assume an acid quality when that insect changes from

Table *of the Combinations of the Sebacic Acid with the Salifiable Bases, in the Order of Affinity*

Bases	*Neutral Salts*
Barytes	Sebate of barytes
Potash	potash
Soda	soda
Lime	lime
Magnesia	magnesia
Ammonia	ammonia
Argill	argill
Oxide of zinc	zinc
manganese	manganese
iron	iron
lead	lead
tin	tin
cobalt	cobalt
copper	copper
nickel	nickel
arsenic	arsenic
bismuth	bismuth
mercury	mercury
antimony	antimony
silver	silver

Note — All these were unknown to the ancient chemists — Author

[1] These combinations named *bombates* were unknown to the ancient chemists and the affinities of the salifiable bases with the bombic acid are undetermined — Author.

a larva to a chrysalis At the moment of its escape from the latter to the butterfly form, it emits a reddish liquor which reddens blue paper, and which was first attentively observed by M Chaussier of the Dijon Academy, who obtains the acid by infusing silk worm chrysalids in alcohol which dissolves their acid without being charged with any of the gummy parts of the insect and by evaporating the alcohol, the acid remains tolerably pure The properties and affinities of this acid are not hitherto ascertained with any precision, and we have reason to believe that analogous acids may be procured from other insects The radical of this acid is probably, like that of the other acids from the animal kingdom, composed of charcoal, hydrogen and azote, with the addition, perhaps, of phosphorus

Section XLII

Observations upon Sebacic Acid and its Combinations with Salifiable Bases

[illegible]

water, it is, however, separated from the fatty [illegible]

again crystallized After this we pour on a proper quantity of sulphuric acid, and the sebacic acid passes over by distillation

Section XLIII

Observations upon Lithic Acid and its Combinations with Salifiable Bases[1]

From the later experiments of Bergman and Scheele, the urinary calculus appears to be a species of salt with an earthy basis it is slightly acidulous, and requires a large quantity of water for [illegible] scarcely [illegible]

lithic acid, the nature and properties of which are as yet very little known There is some appearance that it is an acidulous neutral salt or acid combined in excess with a salifiable base, and I have reason to believe that it really is an acidulous phosphate of lime, if so, it must be excluded from the class of peculiar acids

Table *of the Combinations of the Prussic Acid with the Salifiable Bases in the Order of Affinity*

Bases	*Neutral Salts*
Potash	Prussiate of potash
Soda	soda
Ammonia	ammonia
Lime	lime
Barytes	barytes
Magnesia	magnesia
Oxide of zinc	zinc
iron	iron
manganese	manganese
cobalt	cobalt
nickel	nickel
lead	lead
tin	tin
copper	copper
bismuth	bismuth
antimony	antimony
arsenic	arsenic
silver	silver
mercury	mercury
gold	gold
platinum	platinum

Note—All these were unknown to former chemists —Author

Section XLIV

Observations upon the Prussic Acid and its Combinations with Salifiable Bases

Although this acid combines with alkalies, earths, and metals, in the same way with other acids, it possesses only some of the properties we have been used to attribute to acids, and it may consequently be improperly ranked here in the class of acids, but, as I have already observed, it is difficult to form a decided opinion upon the nature of this substance until the subject has been farther elucidated by a greater number of experiments

THIRD PART

Description of the Instruments and Operations of Chemistry

INTRODUCTION

In the two former parts of this work I designedly avoided being particular in describing the

processes and of plates interrupt the chain of ideas and render the attention necessary both difficult and tedious to the reader On the other hand, if I had confined myself to the summary descriptions hitherto given beginners could have only acquired very vague conceptions of practical chemistry from my work and must have wanted both confidence and interest in operations they could neither repeat nor thoroughly comprehend This want could not have been supplied from books for besides that there are not any which describe the modern instruments and experiments sufficiently at large any work that could have been consulted

Influenced by these motives I determined to reserve for a third part of my work a summary description of all the instruments and manipulations relative to elementary chemistry I considered it as better placed at the end rather than at the beginning of the book because I must have been obliged to suppose the reader acquainted with circumstances which a beginner cannot know and must therefore have read *the elementary part to become acquainted* with The whole of this third part may therefore be considered as resembling the explanations of plates which are usually placed at the end of academic memoirs that they may not interrupt the connection of the text by lengthened description Though I have taken great pains to render this part clear and methodical and have not omitted any essential instrument or apparatus I am far from pretending by it to set aside the necessity of attendance upon lectures and laboratories for such as wish to acquire accurate knowledge of the science of chemistry These should familiarise themselves to the employment of apparatus and to the performance of experiments by actual experience *Nihil est in intellectu quod non prius fuerit in sensu* the motto which the celebrated Rou

teachers or students of chemistry

Chemical operations may be naturally divided into several classes according to the purposes they are intended for performing Some may be considered as purely mechanical such

performed by means of chemical powers and agents such are solution fusion &c Some of these are intended for separating the elements of bodies from each other some for reuniting these elements together and some as combustion, produce both these effects during the same process

Without rigorously endeavouring to follow the above method I mean to give a detail of the chemical operations in such order of ar

modern chemistry because these are little known by men who have devoted much of their *time to chemistry and even by many professors* of the science

CHAPTER I

Of the Instruments Necessary for Determining the Absolute and Specific Gravities of Solid and Liquid Bodies

The best method known for determining the quantities of substances submitted to chemical experiment or resulting from them is by means

of an accurately constructed beam and scales, with *properly regulated weights*, which well known operation is called *weighing* The denomination and quantity of the weights used as an unit or standard for this purpose are extremely arbitrary, and vary not only in different kingdoms, but even *in different provinces* of the same kingdom, and in different cities of the same province This variation is of infinite consequence to be well understood in commerce and in the arts, but, in *chemistry, it is of no* moment what particular denomination of weight be employed, provided the results of experiments be expressed in convenient fractions of the same denomination For this purpose, until *all the weights used in society be reduced to* the same standard, it will be sufficient for chemists in different parts to use the common pound of their own country as the unit or standard, and *to express all its fractional parts in decimals* instead of the arbitrary divisions now in use By this means the chemists of all countries will be thoroughly understood by each other, as, although the absolute weights of the ingredients and products cannot be known, they will readily, and without calculation, be able to determine the relative proportions of these to each other with the utmost accuracy, so that *in this way we shall be possessed of an universal* language for this part of chemistry

With this view I have long projected to have the pound divided into decimal fractions, and I have of late *succeeded through the assistance* of M Fourche, balance-maker at Paris, who has executed it for me with great accuracy and judgment I recommend to all who carry on experiments to *procure similar divisions of the* pound, which they will find both easy and simple in its application, with a very small knowledge of decimal fractions [1]

As the usefulness and accuracy of chemistry depend entirely upon the determination of the weights of the ingredients and products both before and after experiments, too much precision cannot be employed in this part of the subject, and, *for this purpose, we must be provided* with good instruments As we are often obliged, in chemical processes, to ascertain, within a grain or less, the tare or weight of large and heavy *instruments, we must* have beams made with peculiar niceness by accurate workmen, and these must always be kept apart *from the laboratory in some place where the* vapours of acids, or other corrosive liquors, cannot have access; otherwise the steel will rust, and the accuracy of the balance be destroyed I have three sets, of different sizes, *made by M Fontin with the utmost nicety*, and, excepting those made by M Ramsden of London, I do not think any can compare with them for precision and sensitivity The largest of these *is about three feet long in the beam* for large weights, up to fifteen or twenty pounds, the second, for weights of eighteen or twenty ounces, is exact to a tenth part of a grain, and the smallest, calculated only for weighing about *one gros, is sensibly affected by the five* hundredth part of a grain

Besides these nicer balances, which are only used for experiments of research, we must have *others of less value for the ordinary purposes of* the laboratory A large iron balance, capable of weighing forty or fifty pounds within half a dram, one of a middle size, which may ascertain eight or ten pounds, within ten or twelve grains, and a small one, *by which about a* pound may be determined, within one grain

We must likewise be provided with weights divided into their several fractions, both *vulgar and decimal, with the utmost nicety, and* verified by means of repeated and accurate trials in the nicest scales, and it requires some experience, and to be accurately acquainted with the different weights, *to be able to use* them properly The best way of precisely ascertaining the weight of any particular substance is to weigh it twice, once with the *decimal divisions of the pound and another time* with the common subdivisions or vulgar fractions, and, by comparing these, we attain the utmost accuracy

By the specific gravity of any substance is understood the quotient of its absolute weight divided by its magnitude, or, what is the same, the weight of a determinate bulk of any body The weight of a determinate magnitude of water has been generally assumed as unity for this purpose, and we express the specific gravity of gold, sulphuric acid, &c by saying that gold is nineteen times, and sulphuric acid twice *the weight of water, and so of other bodies*

It is the more convenient to assume water as unity in specific gravities, that those substances whose specific gravity we wish to determine are *most commonly weighed in water for* that purpose Thus, if we wish to determine the spe-

[1] M Lavoisier's very accurate directions for reducing the common subdivisions of the French pound into decimal fractions and *vice versa* given in tables subjoined to this 3d part are not printed in this edition —TRANSLATOR.

cific gravity of gold flattened under the hammer, and supposing the piece of gold to weigh 8 *oz* 4 *gros* 2½ *grs* in the air,[1] it is suspended by means of a fine metallic wire under the scale of a hydrostatic balance so as to be entirely immersed in water and again weighed The piece of gold in Mr Brisson s experiment lost by this means 3 *gros* 37 *grs* and as it is evident that the weight lost by a body weighed in water is precisely equal to the weight of the water displaced, or to that of an equal volume

ner with all solid substances We have rarely any occasion in chemistry, to determine the specific gravity of solid bodies, unless when operating upon alloys or metallic glasses but we have very frequent necessity to ascertain that of fluids, as it is often the only means of judging of their purity or degree of concentration

This object may be very fully accomplished with the hydrostatic balance by weighing a solid body such for example as a little ball of rock crystal suspended by a very fine gold wire, first in the air, and afterwards in the fluid whose specific gravity we wish to discover The weight lost by the crystal when weighed in the liquor, is equal to that of an equal bulk of the liquid By repeating this operation successively in water and different fluids we can very readily ascertain, by a simple and easy calculation, the relative specific gravities of these fluids either with respect to each other or to water This

containing very small portions of salt in solution

rather of silver, loaded at its bottom, *bcf*, with tin, as represented swimming in a jug of water, *lmno* To the upper part of the cylinder is attached a stalk of silver wire not more than three fourths of a line diameter surmounted by a little cup *d* intended for containing weights upon the stalk a mark is made at *g* the use of which we shall presently explain This cylinder may be made of any size but, to be accurate, ought at least to displace four

than half a dram or a dram at most to make it sink to *g*

We must first determine, with great precision, the exact weight of the instrument and the number of additional grains requisite for making it sink in distilled water of a determinate temperature to the mark We then perform the same experiment upon all the fluids

ferences which escape the most accurate chemical analysis I shall at some future period give an account of a very extensive set of experiments which I have made upon this subject

These metallic hydrometers are only to be used for determining the specific gravities of such waters as contain only neutral salts or alkaline substances and they may be constructed with different degrees of ballast for alcohol and other spiritous liquors When the specific

actly correspond to the fractions of grains in the different liquors they may be rendered very useful in calculation

What is said in this chapter may suffice without further enlargement for indicating the means of ascertaining the absolute and specific

[1] Vide Mr Brisson s *Essay upon Specific Gravity* p 5 —Author.

gravities of solids and fluids, as the necessary instruments are generally known, and may easily be procured But, as the instruments I have used for measuring the gases are not anywhere described, I shall give a more detailed account of these in the following chapter

CHAPTER II

Of Gazometry, or the Measurement of the Weight and Volume of Aeriform Substances

SECTION I *Of the Pneumato-chemical Apparatus*

THE French chemists have of late applied the name of *pneumato-chemical apparatus* to the very simple and ingenious contrivance, invented by Dr Priestley, which is now indispensably necessary to every laboratory This consists of a wooden trough of larger or smaller dimensions as is thought convenient, lined with plate-lead or tinned copper as represented in perspective, Plate v In *Fig 1* the *same trough or cistern is supposed to have two of its sides* cut away, to show its interior construction more distinctly In this apparatus, we distinguish between the shelf ABCD (*Figs 1* and 2) and the bottom or body of the cistern FGHI (*Fig 2*) The jars *or bell-glasses* are filled with *water in this deep part and* being turned with their *mouths* downwards are afterwards set upon the shelf ABCD, as shown (*Plate* x *Fig 1*, F) The upper parts of the sides of the cistern above the level of the shelf are called the *rim or borders*

The cistern ought to be filled with water so as to stand at least an inch and a half deep upon the shelf, and it should be of such dimensions as to admit of at least one foot of water in every direction in the well This size is sufficient for ordinary occasions but *it is often convenient, and even necessary, to have more room I would therefore advise* such as intend to employ themselves usefully in chemical experiments, to have this apparatus made of considerable magnitude, where their place of operating will allow The well *of my principal cistern holds four cubic feet of water,* and its shelf has a surface of fourteen square feet yet, in spite of this size, which I at first thought immoderate, I am often straitened for room

In laboratories, where a *considerable number of experiments are performed, it is* necessary to have several lesser cisterns, besides the large one, which may be called the *general magazine* and even some portable ones which may be moved, when *necessary, near a furnace or wherever they may be wanted* There are likewise some operations which dirty the water of the apparatus and therefore require to be carried on in cisterns by themselves

It were doubtless *considerably cheaper* to use cisterns, or *iron bound tubs, of wood* simply dove-tailed, instead of being lined with lead or copper, and in my first experiments I used them made in that way but I soon discovered *their inconvenience If the water be not always* kept at the same level, *such of the dovetails* as are left dry shrink, and when more water is added it escapes through the joints, and runs out

We *employ crystal jars* or bell-glasses, (Plate v, *Fig 9*, A) *for containing the* gases in this apparatus, and for transporting these, when full of gas, from one cistern to another, or for keeping them in reserve when the cistern is too full, we make use of a flat dish BC, surrounded by a standing up *rim or border, with two* handles DE *for* carrying it by

After several trials of different materials, I have found marble the best substance for constructing the mercurial pneumato-chemical apparatus, as it is perfectly impenetrable by mercury, *and is not liable, like wood, to separate at the junctures, or to allow the mercury to escape* through chinks, neither does it run the risk of breaking like glass, stone-ware, or porcelain Take a block of marble BCDE (Plate v, *Figs 3* and *4*), about two feet long, 15 or 18 inches broad and ten inches thick, and cause it to be hollowed out as at *mn* (*Fig 5*) about four inches deep as a reservoir for the mercury, and, to be able more conveniently to fill the jars cut the gutter TV (*Figs 3*, *4*, and *5*) at least four inches deeper and, as this trench may sometimes *prove troublesome, it is made capable of being covered at pleasure by thin* boards, which slip into the *grooves xy*, (*Fig 5*) I have two marble cisterns upon this construction of different sizes [illegible]
ways emplo[illegible]
cur[illegible]
any[illegible]
turr[illegible] *operate*
will[illegible] this apparatus exactly as with
water in the one before described, but the bell glasses must be of smaller diameter and much stronger, or we may use glass tubes, having their mouths widened, as in *Fig 7*, these are called *eudiometers* by the glass men who sell them One of the bell glasses *is represented*,

Fig 5, A, standing in its place, and what is called a *jar* is engraved *Fig 6*

The mercurial pneumato-chemical apparatus is necessary in all experiments wherein the disengaged gases are capable of being absorbed by water, as is frequently the case, especially in all combinations, excepting those of metals, in fermentation, &c

SECTION II *Of the Gazometer*

I give the name of *gazometer* to an instrument which I invented and caused constructed, for the purpose of a kind of bellows which might furnish an uniform and continued stream of oxygen gas in experiments of fusion M Meusnier and I have since made very considerable *corrections and additions, having converted* it into what may be called an *universal instrument*, without which it is hardly possible to perform most of the very exact experiments The name we have given the instrument indicates its intention for measuring the volume or quantity of gas submitted to it for examination

Instead of being poised as in ordinary balances, this beam rests, by means of a cylindrical axis of polished steel F (*Fig 9*), upon two large moveable brass friction wheels, by which the resistance to its motion from friction is considerably diminished, being converted into friction of the second order As an additional precaution, the parts of these wheels which support the axis of the beam are covered with plates of polished rock crystal The whole of this machinery is fixed to the top of the solid column of wood BC (*Fig 1*) To one extremity

or shortening, by being less or more charged with weight, to this chain, an iron trivet, with three branches, *ai*, *ci*, and *hi*, is strongly fixed at *i* and these branches support a large inverted jar A, of hammered copper, of about 18

terior structure

Round the bottom of the jar, on its outside, is fixed (Plate IX, *Fig 2*) a border divided into compartments 1, 2, 3, 4, &c, intended to receive leaden weights separately represented 1, 2, 3, *Fig 3* These are intended for increasing the weight of the jar when a considerable pressure is requisite, as will be afterwards explained, though such necessity seldom occurs The cylindrical jar A is entirely open below, *de* (Plate IX, *Fig 4*), but is closed above with a copper lid, *abc*, open at *bf*, and capable of being shut by the cock *g* This lid, as may be seen by inspecting the figures, is placed a few inches within the top of the jar to prevent the jar from being ever entirely immersed in the water and covered over Were I to have this instrument *made over again, I should cause the lid to be* considerably more flattened, so as to be almost level This jar or reservoir of air is contained in the cylindrical copper vessel LMNO (Plate VIII, *Fig 1*) filled with water

In the middle of the cylindrical vessel LMNO (Plate IX, *Fig 4*) are placed two tubes *st*, *xy*, which are made to approach each other at their

pleasure, by loading the scale P less or more by means of weights When gas is to be introduced into the machine, the pressure is taken off, or even rendered negative, but, when gas is to be expelled, a pressure is made with such degree of force as is found necessary

The third tube 12, 13, 14, 15, is intended for conveying air or gas to any necessary place or apparatus for combustions, combinations, or any other experiment in which it is required

To explain the use of the fourth tube, I must enter into some discussions Suppose the vessel LMNO (Plate VIII, *Fig 1*) full of water, and the jar A partly filled with gas, and partly with water, it is evident that the weights in the basin P may be so adjusted as to occasion an exact equilibrium between the weight of the basin and of the jar, so that the external air shall not tend to enter into the jar nor the gas to escape from it, and in this case the water will stand exactly at the same level both within and without the jar On the contrary, if the weight in the basin P be diminished, the jar will then press downwards from its own gravity, and the water will stand lower within the jar than it does without in this case, the included air or gas will suffer a degree of compression above that experienced by the external air, exactly proportioned to the weight of a column of water, equal to the difference of the external and internal surfaces of the water From these reflections M Meusnier contrived a method of determining the exact degree of pressure to which the gas contained in the jar is at any time exposed For this purpose he employs a double glass siphon 19, 20, 21, 22, 23, firmly cemented at 19 and 23 The extremity 19 of this siphon communicates freely with the water in the external vessel of the machine, and the extremity 23 communicates with the fourth tube at the bottom of the cylindrical vessel, and consequently, by means of the perpendicular tube *st* (Plate IX, *Fig 4*) with the air contained in the jar He likewise cements, at 16 (Plate VIII, *Fig 1*), another glass tube 16, 17, 18, which communicates at 16 with the water in the exterior vessel LMNO, and, at its upper end 18, is open to the external air

By these several contrivances, it is evident that the water must stand in the tube 16, 17, 18, at the same level with that in the cistern LMNO, and, on the contrary, that, in the branch 19, 20, 21, it must stand higher or lower according as the air in the jar is subjected to a greater or lesser pressure than the external air To ascertain these differences, a brass scale divided into inches and lines is fixed between these two tubes It is readily conceived that, as air, and all other elastic fluids must increase in weight by compression, it is necessary to know their degree of condensation to be enabled to calculate their quantities and to convert the measure of their volumes into correspondent weights, and this object is intended to be fulfilled by the contrivance now described

But, to determine the specific gravity of air or of gases, and to ascertain their weight in a known volume, it is necessary to know their temperature as well as the degree of pressure under which they subsist, and this is accomplished by means of a small thermometer, strongly cemented into a brass collet which screws into the lid of the jar A This thermometer is represented separately, Plate VIII, *Fig 10*, and in its place 24, 25, *Fig 1* and Plate IX, *Fig 4*. The bulb is in the inside of the jar A, and its graduated stalk rises on the outside of the lid

The practice of gazometry would still have laboured under great difficulties without further precautions than those above described When the jar A sinks in the water of the cistern LMNO, it must lose a weight equal to that of the water which it displaces, and consequently the compression which it makes upon the contained air or gas must be proportionally diminished Hence the gas furnished, during experiments from the machine, will not have the same density towards the end that it had at the beginning, as its specific gravity is continually diminishing This difference may, it is true, be determined by calculation but this would have occasioned such mathematical investigations as must have rendered the use of this apparatus both troublesome and difficult M Meusnier has remedied this inconvenience by the following contrivance A square rod of iron, 26, 27 (Plate VIII, *Fig 1*), is raised perpendicular to the middle of the beam DE This rod passes through a hollow box of brass 28, which opens, and may be filled with lead, and this box is made to slide alongst the rod by means of a toothed pinion playing in a rack, so as to raise or lower the box and to fix it at such places as is judged proper

When the lever or beam DE stands horizontal, this box gravitates to neither side, but, when the jar A sinks into the cistern LMNO, so as to make the beam incline to that side, it is evident the loaded box 28, which then passes beyond the center of suspension, must gravitate to the side of the jar and augment its

pressure upon the included air This is increased in proportion as the box is raised towards 27,

alongst the rod 26, 27, we can augment or diminish the correction it is intended to make upon the pressure of the jar, and both experience and calculation show that this may be made to compensate very exactly for the loss of weight in the jar at all degrees of pressure

I have not hitherto explained the most important part of the use of this machine which

rigorous precision and likewise the quantity supplied to the machine from experiments we fixed to the arc which terminates the arm of

and the lowering of this end of the beam is measured by the fixed index 29, 30 which has a nonius giving hundredth parts of a degree at its extremity 30

The whole particulars of the different parts of the above described machine are represented in Plate VIII as follow

Fig 2 is the flat chain invented by M Vaucanson and employed for suspending the scale or basin P, *Fig 1* but, as this lengthens or shortens according as it is more or less loaded, it would not have answered for suspending the jar A, *Fig 1*

Fig 5 is the chain ikm, which in *Fig 1* sustains the jar A This is entirely formed of plates

vertical position

Fig 3 The iron rod 26, 27 which is fixed perpendicular to the center of the beam, with its box 28

Figs 7 & 8 The friction wheels with the plates of rock crystal Z as points of contact by which the friction of the axis of the lever of the balance is avoided

Fig 4 The piece of metal which supports the axis of the friction wheels

Fig 9 The middle of the lever or beam, with the axis upon which it moves

Fig 10 The thermometer for determining the temperature of the air or gas contained in the jar

endeavour, by repeated trials, to discover at

ferences of a quarter, or even of half a line are not of any consequence This height of the box 28 is not the same for every degree of pressure, but varies according as this is of one two three or more inches All these should be registered with great order and precision

We next take a bottle which holds eight or ten pints the capacity of which is very accurately determined by weighing the water it is capable of containing This bottle is turned

index 30 upon the sector ml is accurately observed, then by opening the stop-cock 8, and

now observed, and we calculate what number

The instrument I have been describing was constructed with great accuracy and uncommon skill by M Meignie Jr engineer and physical instrument-maker It is a most valuable instrument, from the great number of pur

poses to which it is applicable, and, indeed, there are many experiments which are almost *impossible to perform without it* It becomes expensive, because in many experiments, such as the formation of water and of nitric acid, it is absolutely necessary to employ two of the same machines In the present advanced state of chemistry, very expensive and complicated instruments are become indispensably necessary for ascertaining the analysis and synthesis of bodies with the requisite precision as to quantity and proportion, it is certainly proper to endeavour to simplify these and to render them less costly, but this ought by no means to be attempted at the expense of their convenience of application and much less of their accuracy

SECTION III *Some Other Methods of Measuring the Volume of Gases*

The gazometer described in the foregoing section is too costly and too complicated for being generally used in laboratories for measuring the gases and is not even applicable to every circumstance of this kind In numerous series of experiments more simple and more readily applicable methods must be employed For this purpose I shall describe the means I used before I was in possession of a gazometer and which I still use in preference to it in the ordinary course of my experiments

Suppose that, after an experiment there is a *residuum of gas* neither absorbable by alkali nor water, contained in the upper part of the jar AEF (Plate IV, *Fig 3*) standing on the shelf of a pneumato-chemical apparatus, of which we wish to ascertain the quantity We must first mark the height to which the mercury or water rises in the jar with great exactness, by means of slips of paper pasted in several parts round the jar If we have been operating in mercury, we begin by displacing the mercury from the jar by introducing water in its stead This is readily done by filling a bottle quite full of water, having stopped it with your finger, turn it up, and introduce its mouth below the edge of the jar, then turning down its body again, the mercury, by its gravity, falls into the bottle, and the water rises in the jar, and takes the place occupied by the mercury When this is accomplished, pour so much water into the cistern ABCD as will stand about an inch over the surface of the mercury, then pass the dish BC (Plate V, *Fig 9*) under the jar, and carry it to the water cistern (*Figs 1* and *2*) We here exchange the gas into another jar, which has been previously graduated in the manner to be afterwards described, and we thus judge of the quantity or volume of the gas by means of the degrees which it occupies in the graduated jar

There is another method of determining the volume of gas, which may either be substituted in place of the one above described or may be usefully employed as a correction or proof of that method After the air or gas is exchanged from the first jar, marked with slips of paper, into the graduated jar, turn up the mouth of the marked jar and fill it with water exactly to the marks EF (Plate , *Fig 3*) and by weighing the water we determine the volume of the air or gas it contained, allowing one cubic foot, or 1728 cubic inches of water for each 70 pounds, French weight

The manner of graduating jars for this purpose is very easy, and we ought to be provided with several of different sizes, and even several of each size in case of accidents Take a tall, narrow, and strong glass jar, and having filled it with water in the cistern (Plate V, *Fig 1*), place it upon the shelf ABCD we ought always to use the same place for this operation, that the level of the shelf may be always exactly similar, by which almost the only error to which this process is liable will be avoided Then take a narrow mouthed phial which holds exactly 6 *oz 3 gros 61 grs* of water, which corresponds to 10 cubic inches If you have not one exactly of this dimension, choose one a little larger, and diminish its capacity to the size requisite by dropping in a little melted wax and rosin This bottle serves the purpose of a standard for gauging the jars Make the air contained in this bottle pass into the jar and mark exactly the place to which the water has descended, add another measure of air and again mark the place of the water, and so on, till all the water be displaced It is of great consequence that, during the course of this operation, the bottle and jar be kept at the same temperature with the water in the cistern and, for this reason, we must avoid keeping the hands upon either as much as possible, or, if we suspect they have been heated, we must cool them by means of the water in the cistern The height of the barometer and thermometer during this experiment is of no consequence

When the marks have been thus ascertained upon the jar for every ten cubic inches, we engrave a scale upon one of its sides by means of a diamond pencil Glass tubes are graduated in the same manner for use in the mercurial apparatus, only they must be divided into cubic

inches and tenths of a cubic inch The bottle used for gauging these must hold 8 *oz* 6 *gros* 25 *grs* of mercury which exactly corresponds to a cubic inch of that metal

The method of determining the volume of air or gas by means of a graduated jar has the

it requ res corrections with respect to the height of the barometer and thermometer But when we ascertain the volume of air by we gh ng the water which the jar is capable of containing up to the marks EF it is necessary to make a further correction for the difference between the surface of the water in the cistern and the height to which it r ses within the jar This will be explained in the fifth section of this chapter

SECTION IV *Of the Method of Separating the Different Gases from Each Other*

As experiments often produce two three or more species of gas it is necessary to be able to separate these from each other that we may as certain the quantity and species of each Suppose that under the jar A (Plate IV *Fig 3*) is contained a quantity of d fferent gases mixed

the surface of the mercury If the mixture of gas contains any muriatic or sulphurous acid gas a rapid and cons derable absorption will instantly take place from the strong tendency these two gases have especially the former to combine with or be absorbed by water If the

ter apparatus It is likewise necessary to regis ter the difference between the surface of the mercury in the cistern and that in the jar and the height of the barometer and thermometer at the end of each experiment

When all the gas or gases absorbable by water and potash are absorbed water is admitted into the jar to displace the mercury and as is described in the preceding section the mercury in the cistern is to be covered by one or two inches of water After this the jar is to be transported by means of the flat dish BC (Plate v

in little jars to ascertain nearly the nature of the gas in question For instance into a small jar full of the gas (Plate v *Fig 8*) a lighted taper is introduced if the taper is not immediately extinguished we conclude the gas to contain oxygen gas and in proportion to the brightness of the flame we may judge if it contain

ju lge it cons sts of carbonated hydrogen gas and if it takes fire with a sudden deflagration

duced we conclude that it contains nitrous gas

These preliminary trials give some general

purpose all the methods of analysis may be employed and to direct the e properly it is of great use to have a previous approx mation by the above methods Suppose for instance we know that the re iduum cons sts of oxygen an l

hydrogen gas, these are deflagrated together by means of the electrical spark, fresh portions

process water is formed, which is immediately absorbed by the water of the apparatus, but, if the hydrogen gas contain charcoal, carbonic acid is formed at the same time, which is not absorbed so quickly, the quantity of this is

nearly ascertain its quantity from the diminution produced by this mixture

I confine myself to these general examples, which are sufficient to give an idea of this kind of operation, a whole volume would not serve to explain every possible case It is necessary to become familiar with the analysis of gases by long experience we must even acknowledge that they mostly possess such powerful affinities to each other that we are not always certain of having separated them completely In these cases, we must vary our experiments in every possible point of view, add new agents to the combination, and keep out others, and continue our trials till we are certain of the truth and exactitude of our conclusions

SECTION V *Of the Necessary Corrections of the Volume of Gases, According to the Pressure of the Atmosphere*

All elastic fluids are compressible or condensable in proportion to the weight with which they are loaded Perhaps this law, which is ascertained by general experience, may suffer some irregularity when these fluids are under a degree of condensation almost sufficient to reduce them to the liquid state, or when either in a state of extreme rarefaction or condensation but we seldom approach either of these limits with most of the gases which we submit to our experiments I understand this proposi-

which a column of mercury stands in equilibrium with a column of air of the same weight. But it is unnecessary to prolongate the branch CD to such a height, as it is evident that the barometer, being immersed in air, the column of mercury AB will be equally in equilibrium with a column of air of the same diameter, though the leg CD be cut off at C, and the part

the highest part of the atmosphere to the surface of the earth, is about twenty-eight French inches in the lower parts of the city of Paris, or, in other words, the air at the surface of the earth at Paris is usually pressed upon by a weight equal to that of a column of mercury twenty-eight inches in height I must be understood in this way in the several parts of this publication when talking of the different gases, as, for instance, when the cubic foot of oxygen gas is said to weigh 1 *oz* 4 *gros*, under 28 inches pressure The height of this column of mercury, supported by the pressure of the air, diminishes in proportion as we are elevated above the surface of the earth, or rather above the level of the sea, because the mercury can only form an equilibrium with the column of air which is above it and is not in the smallest degree affected by the air which is below its level

In what ratio does the mercury in the barometer descend in proportion to its elevation, or, which is the same thing, according to what law or ratio do the several strata of the atmosphere decrease in density? This question, which has exercised the ingenuity of natural philosophers during the last century, is considerably elucidated by the following experiment

If we take the glass siphon ABCDE (Plate XII, *Fig* 17), shut at E and open at A, and in-

mon with the whole surrounding air, by a weight or column of air equal to 28 inches of mercury But, if we pour 28 inches of mercury into the leg AB, it is plain the air in the branch BCDE will now be pressed upon by a weight equal to twice 28 inches of mercury, or twice the weight of the atmosphere, and experience shows that, in this case, the included air, instead of filling the tube from B to E, only occupies from C to E, or exactly one half of the space it filled before If to this first column of mercury we add two other portions of 28 inches each, in the branch AB, the air in the branch

BCDE will be pressed upon by four times the weight of the atmosphere, or four times the weight of 28 inches of mercury, and it will then only fill the space from D to E, or exactly one quarter of the space it occupied at the commencement of the experiment From these experiments, which may be infinitely varied, has been deduced as a general law of nature, which seems applicable to all permanently elastic fluids, that they diminish in volume in proportion to the weights with which they are pressed upon, or, in other words *"the volume of all elastic fluids is in the inverse ratio of the weight by which they are compressed"*

The experiments which have been made for measuring the heights of mountains by means of the barometer confirm the truth of these deductions, and, even supposing them in some degree inaccurate, these differences are so extremely small that they may be reckoned as nullities in chemical experiments When this law of the compression of elastic fluids is once well understood, it becomes easily applicable to the corrections necessary in pneumato-chemical experiments upon the volume of gas in relation to its pressure These corrections are of two kinds, the one relative to the variations of the barometer and the other for the column of water or mercury contained in the jars I shall endeavour to explain these by examples, beginning with the most simple case

Suppose that 100 cubic inches of oxygen gas are obtained at 10° (54 5°) of the thermometer, and at 28 inches 6 lines of the barometer, it is required to know what volume the 100 cubic inches of gas would occupy, under the pressure of 28 inches,[1] and what is the exact weight of the 100 inches of oxygen gas? Let the unknown volume, or the number of inches this gas would [illegible]

[illegible]

weight of this gas occupying 100 cubic inches, under 28 5 inches of barometrical pressure, for, as it corresponds to 101 786 cubic inches at the pressure of 28, and as, at this pressure, and at 10° (54 5°) of temperature, each cubic inch of oxygen gas weighs half a grain, it follows that 100 cubic inches, under 28 5 barometrical pressure, must weigh 50 893 grains This conclusion might have been formed more directly, as, since the volume of elastic fluids is in the inverse ratio of their compression, their weights must be in the direct ratio of the same compression hence, since 100 cubic inches weigh 50 grains under the pressure of 28 inches, we have the following statement to determine the weight of 100 cubic inches of the same gas at 28 5 barometrical pressure, 28 50 28.5 x, the unknown quantity, = 50 893

The following case is more complicated Suppose the jar A (Plate XII, *Fig 18*) to contain a [illegible]

at 27 5 inches It is evident from these data that the air contained in ACD is pressed upon by the weight of the atmosphere, diminished [illegible]

rometer, and consequently occupies more space than it would occupy at the mean pressure, [illegible]

$$x = \frac{[illegible]}{28} = 92\ 143 \text{ cubic inches}$$

[illegible]

[1] According to the proportion of 114 to 107 given between the French and English foot 28 inches of the French barometer are equal to 29 83 inches of the English —TRANSLATOR

In experiments performed in the water-apparatus, we must make similar corrections to

the surface of the water in the cistern But, as the pressure of the atmosphere is expressed in inches and lines of the mercurial barometer, and as homogeneous quantities only can be calculated together, we must reduce the observed inches and lines of water into corre-

times heavier than water[1]

SECTION VI *Of the Correction Relative to the Degrees of the Thermometer*

mometrical temperature, because, all elastic fluids being expanded by heat and condensed by cold, their weight in any determinate volume is thereby liable to considerable alterations As the temperature of 10° (54 5°) is a medium between the heat of summer and the cold of winter, being the temperature of subterraneous places and that which is most easily approached to at all seasons, I have chosen that degree as a mean to which I reduce air or gas in this species of calculation

M de Luc found that atmospheric air was increased 1/215 part of its bulk, by each degree of a mercurial thermometer, divided into 81 de-

lated 1/180 we have not any exact experiments hitherto published respecting the ratio of dilatation of the other gases but, from the trials which have been made, their dilatation seems to differ little from that of atmospheric air

part, and hydrogen gas 1/190 part for each de-

[1] The appendix is omitted in this edition — EDITOR.

possible to the standard of 10° (54 5°), by this means any errors in correcting the weight or volume of gases by reducing them to the common standard, will become of little moment

The calculation for this correction is extremely easy Divide the observed volume of air by 210 and multiply the quotient by the degrees of temperature above or below 10° (54 5°) This correction is negative when the actual temperature is above the standard and positive when below By the use of logarithmical tables this calculation is much facilitated

SECTION VII *Example for Calculating the Corrections Relative to the Variations of Pressure and Temperature*

CASE

In the jar A (Plate IV, *Fig 3*), standing in a water-apparatus, is contained 353 cubic inches of air the surface of the water within the jar at EF is 4½ inches above the water in the cistern, the barometer is at 27 inches 9½ lines, and the thermometer at 15° (65 75°) Having burnt a quantity of phosphorus in the air, by which concrete phosphoric acid is produced, the air after the combustion occupies 295 cubic inches, the water within the jar stands 7 inches above that in the cistern, the barometer is at 27 inches 9¼ lines, and the thermometer at 16° (68°) It is required from these data to determine the actual volume of air before and after combustion and the quantity absorbed during the process

Calculation before Combustion

The air in the jar before combustion was 353 cubic inches, but it was only under a barometrical pressure of 27 inches 9½ lines, which, reduced to decimal fractions, gives 27 79167 inches and from this we must deduct the difference of 4½ inches of water, which corresponds to 0 33166 inches of the barometer hence the real pressure of the air in the jar is 27 46001 As the

barometrical pressure

353:x, the unknown volume, :27 46001:28

Hence, $x = \dfrac{353 \times 27\ 46001}{28} = 346\ 192$ cubic inches, which is the volume the same quantity of air would have occupied at 28 inches of the barometer.

The 210th part of this corrected volume is 1 65, which, for the five degrees of temperature above the standard gives 8 255 cubic inches, and, as this correction is subtractive, the real corrected volume of the air before combustion is 337 942 inches

Calculation after Combustion

By a similar calculation upon the volume of *air after* combustion, we find its barometrical pressure 27 77083 − 0 51593 = 27 25490 Hence, to have the volume of air under the pressure of 28 inches, 295 : x :: 27 77083 28 inversely, or, $x = \frac{295 \times 27\ 25490}{28} = 287\ 150$ The 210th part of this corrected volume is 1 368, which, multiplied by 6 degrees of thermometrical difference, gives the subtractive correction for temperature 8 208, leaving the actual corrected volume of air after combustion 278 942 inches

Result

The corrected volume before combustion	337 942
Ditto remaining after combustion	*278 942*
Volume absorbed during combustion	59 000

SECTION VIII *Method of Determining the Absolute Gravity of the Different Gases*

stop-cock fg is fixed by a tight screw This apparatus is connected by the double screw, represented separately at *Fig 12* to the jar BCD, *Fig 10*, which must be some pints larger in dimensions than the balloon This jar is open at top and is furnished with the brass cap hi and stop-cock lm One of these stop-cocks is represented separately at *Fig 11*

neck de, and the last remains of moisture are removed by exhausting it once or twice in an air pump

is left open, the balloon is to be exhausted as completely as possible observing carefully the degree of exhaustion by means of the barometer attached to the air pump When the vacuum is formed, the stop-cock fg is shut and the weight of the balloon determined with the most scrupulous exactitude It is then fixed to the jar BCD, which we suppose placed in water in the shelf of the pneumato-chemical apparatus (*Fig 1*), the jar is to be filled with the gas we mean to weigh, and then, by opening the stopcocks fg and lm, the gas ascends into the balloon, whilst the water of the cistern rises at the same time into the jar To avoid very troublesome corrections, it is necessary, during this first part of the operation to sink the jar in the cistern till the surfaces of the water within the jar and without exactly correspond The stopcocks are again shut and the balloon being unscrewed from its connection with the jar, is to be carefully weighed, the difference between this weight and that of the exhausted balloon

inches contained in the balloon the quotient is *the weight of a cubic foot of the gas or air submitted to experiment*

Exact account must be kept of the barometrical height and temperature of the thermometer during the above experiment and from these the resulting weight of a cubic foot is easily corrected to the standard of 28 inches and 10°, as directed in the preceding section

that barometer, for instance, remains at the

into the balloon

CHAPTER III

Description of the Calorimeter, or Apparatus for Measuring Caloric

chapter are extracted

If, after having cooled any body to the freez-

ing point, it be exposed in an atmosphere of 25° (88 25°), the body will gradually become heated, from the surface inwards, till at last it acquires the same temperature with the surrounding air. But, if a piece of ice be placed in the same situation, the circumstances are quite different it does not approach in the smallest degree towards the temperature of the circumambient air but remains constantly at zero (32°), or the temperature of melting ice, till the last portion of ice be completely melted

This phenomenon is readily explained, as, to *melt ice, or reduce it to water it requires to be* combined with a certain portion of caloric the whole caloric attracted from the surrounding bodies, is arrested or fixed at the surface or external layer of ice which it is employed to dissolve, and combines with it to form water the next quantity of caloric combines with the second layer to dissolve it into water, and so on successively till the whole ice be dissolved or converted into water by combination with caloric the very last atom still remaining at its former temperature, because the caloric has never penetrated so far as long as any intermediate ice remained to melt

Upon these principles, if we conceive a hollow sphere of ice at the temperature of zero (32°) placed in an atmosphere 10° (54 5°) and containing a substance at any degree of temperature above freezing, it follows, 1st that the heat of the external atmosphere cannot penetrate into the internal hollow of the sphere of ice, 2nd that the heat of the body placed in the hollow of the sphere cannot penetrate outwards beyond it but will be stopped at the internal surface and continually employed to melt successive layers of ice, until the temperature of the body be reduced to zero (32°) by having all its superabundant caloric above that temperature carried off by the ice If the whole water, formed within the sphere of ice during the reduction of the temperature of the included body to zero, be *carefully* collected the weight of the water will be exactly proportional to the quantity of caloric lost by the body in passing from its original temperature to that of melting ice, for it is evident that a double quantity of caloric would have melted twice the quantity of ice, hence the quantity of ice melted is a very exact measure of the quantity of caloric employed to produce that effect and consequently of the quantity lost by the only substance that could possibly have supplied it

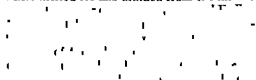
I have made this supposition of what would take place in a hollow sphere of ice for the purpose of more readily explaining the method used in this species of experiment, which was first conceived by M de Laplace It would be difficult to procure such spheres of ice and in convenient to make use of them when got, but, by means of the following apparatus, we have remedied that defect I acknowledge the name of *calorimeter*, which I have given it, as derived partly from Greek and partly from Latin, is in some degree open to criticism, but, in matters of science, a slight deviation from strict etymology, for the sake of giving distinctness of *idea, is excusable, and I could not derive the* name entirely from Greek without approaching too near to the names of known instruments employed for other purposes

The calorimeter is represented in Plate VI It is shown in perspective at *Fig 1*, and its interior structure is engraved in *Figs 2* and *3*, the former being a horizontal, and the latter a perpendicular section Its capacity or cavity is divided into three parts which, for better distinction I shall name the interior, middle, and external cavities The interior cavity *ffff* (*Fig 4*), into which the substances submitted to experiment are put, is composed of a grating or cage of iron wire supported by several iron bars its opening or mouth LM is covered by the lid HG of the same materials The middle cavity *bbbb* (*Figs 2* and *3*) is intended to contain the ice which surrounds the interior cavity, and which is to be melted by the caloric of the substance employed in the experiment. The ice is supported by the grate *mm* at the bottom of the cavity, under which is placed the sieve *nn* These two are represented separately in *Figs 5* and *6*

In proportion as the ice contained in the middle cavity is melted by the caloric disengaged from the body placed in the interior cavity, the water runs through the grate and sieve and falls through the conical funnel *ccd* (*Fig 3*), and tube *xy*, into the receiver F (*Fig 1*) [illegible] water may be retained [illegible] by [illegible] it [illegible] pi [illegible] ca [illegible] surrounding air, an [illegible] ater produced from it is carried off through the pipe ST, which shuts by means of the stop-cock *r* The whole machine is covered by the lid FF (*Fig 7*), made of tin painted with oil colour to prevent rust

When this machine is to be employed, the middle cavity *bbbb* (*Figs 2* and *3*), the lid GH (*Fig 4*) of the interior cavity, the exter-

nal cavity *aaaa* (*Figs 2* and *3*), and the general lid FF (*Fig 7*) are all filled with pounded ice well rammed so that no void spaces remain and the ice of the middle cavity is allowed to drain The machine is then opened, and the substance submitted to experiment being placed in the interior cavity, it is instantly closed After waiting till the included body is completely cooled to the freezing point, and the whole melted ice has drained from the middle



formerly mentioned as included in a hollow sphere of ice, the whole caloric disengaged is stopped by the ice in the middle cavity, and that ice is preserved from being affected by any other heat by means of the ice contained in the general lid (*Fig 7*) and in the external cavity Experiments of this kind last from fifteen to twenty hours they are sometimes accelerated by covering up the substance in the interior cavity with well drained ice, which hastens its cooling

The substances to be operated upon are placed in the thin iron bucket (*Fig 8*), the cover of which has an opening fitted with a cork, into which a small thermometer is fixed When we use acids, or other fluids capable of injuring the metal of the instruments they are contained in the matrass (*Fig 10*), which has a similar thermometer in a cork fitted to its mouth, and which stands in the interior cavity upon the small cylindrical support RS (*Fig 10*)

It is absolutely requisite that there be no communication between the external and middle cavities of the calorimeter, otherwise the

periment

essential that this experiment be carried on in a temperature somewhat above freezing hence, in time of frost, the calorimeter must be kept in an apartment carefully heated It is likewise *necessary that the ice employed be not under* zero (32°), for which purpose it must be pounded and spread out thin for some time in a place of a higher temperature

The ice of the interior cavity always retains a certain quantity of water adhering to its surface, which may be supposed to belong to the result of the experiment, but as, at the beginning of each experiment, the ice is already saturated with as much water as it can contain, if any of the water produced by the caloric should remain attached to the ice, it is evident that very nearly an equal quantity of what adhered to it before the experiment must have run down into the vessel Γ in its stead, for the inner surface of the ice in the middle cavity is very little changed during the experiment

By any contrivance that could be devised, we could not prevent the access of the external air into the interior cavity when the atmosphere was 9° or 10° (52° or 54°) above zero The

and is replaced by the warmer external air, which giving out its caloric to the ice, becomes heavier and sinks in its turn thus a current of air is formed through the machine, which is the

shut but it is better to operate only when the

insensible so that we may answer for the accuracy of our experiments upon the specific heat of bodies to a fortieth part

lids, by which a current of atmospheric air

may be blown into the interior cavity of the machine

It is extremely easy, with this apparatus, to determine the phenomena which occur in operations where caloric is either disengaged or absorbed If we wish, for instance, to ascertain the quantity of caloric which is disengaged from a solid body in cooling a certain number of degrees, let its temperature be raised to 80° (212°), it is then placed in the interior cavity *ffff* (*Figs 2* and *3*) of the calorimeter, and allowed to remain till we are certain that its temperature *is reduced to zero* (32°), *the water pro-*

to experiment, multiplied into the degrees of temperature which it had above zero at the commencement of the experiment, gives the proportion of what the English philosophers call *specific heat*

Fluids are contained in proper vessels, whose specific heat has been previously ascertained, and operated upon in the machine in the same manner as directed for solids, taking care to deduct, from the quantity of water melted during the experiment, the proportion which belongs to the containing vessel

If the quantity of caloric disengaged during the combination of different substances is to be determined, these substances are to be previously reduced to the freezing degree by keeping them a sufficient time surrounded with pounded ice, the mixture is then to be made in the inner cavity of the calorimeter, in a proper vessel likewise reduced to zero (32°), and they are kept inclosed till the temperature of the combination has returned to the same degree The quantity of water produced is a measure of the caloric disengaged during the combination

To determine the quantity of caloric disengaged during combustion and during animal respiration, the combustible bodies are burnt,

for this experiment As the continual renewal of air is absolutely necessary in such experiments, *we blow fresh air into the interior cav-*

pass through pounded ice, that it may be reduced to zero (32°) before it arrives at the calorimeter. The air which escapes must likewise *be made to pass through a tube surrounded* with ice, included in the interior cavity of the machine, and the water which is produced must make a part of what is collected, because the caloric disengaged from this air is part of the product of the experiment

It is somewhat more difficult to determine the specific caloric contained in the different gases, on account of their small degree of density, *for, if they are only placed in the calorimeter* in vessels like other fluids, the quantity of ice melted is so small that the result of the experiment becomes at best very uncertain For this species of experiment we have contrived to make the air pass through two metallic worms, or spiral tubes, one of these, through which the air passes and becomes heated in its way to the calorimeter, is contained in a vessel full of boiling water, and the other, through which the air circulates within the calorimeter to dis-

worm, the temperature of the air, as it enters the calorimeter, is determined, and its temperature in getting out of the interior cavity is found by another thermometer placed at the other end of the worm By this contrivance we are enabled to ascertain the quantity of ice melted by determinate quantities of air or gas, while losing a certain number of degrees of temperature, and, consequently, to determine their several degrees of specific caloric The same apparatus, with some particular precautions, may be employed to ascertain the quantity of caloric disengaged by the condensation of the vapours of different liquids

The various experiments which may be made with the calorimeter do not afford absolute conclusions, but only give us the measure of relative quantities, we have therefore to fix a unit,

en as this unit, and, as it requires a pound of water of the temperature of 60° (167°) to melt *a pound of ice, the quantity of caloric expressed* by our unit or standard point is what raises a pound of water from zero (32°) to 60° (167°) When this unit is once determined, we have

The following is an easy mode of calculation for this purpose applied to one of our earliest experiments

We took 7 *lb* 11 *oz* 2 *gros* 36 *grs* of plate-

the end of eleven hours when the whole quantity of water melted from the ice had thoroughly drained off we found that 1 109/95 pounds of ice were melted Hence the caloric disengaged from the iron by cooling 78° (175 5°) hav

Dividing this quantity by the weight of the

cooling through 60° (135°) of temperature

Fluid substances such as sulphuric and nitric acids &c are contained in a matrass (Plate vi *Fig* 9) having a thermometer adapted to the cork with its bulb immersed in the liquid The matrass is placed in a bath of boiling water and when from the thermometer we judge the liquid is raised to a proper temperature the matrass is placed in the calorimeter The calculation of the products to determine the specific caloric of these fluids is made as above directed taking care to deduct from the water

omitted because not yet sufficiently complete different circumstances having occasioned the series to be interrupted it is not however lost sight of and we are less or more employed upon the subject every winter

CHAPTER IV

Of Mechanical Operations for Division of Bodies

SECTION I *Of Trituration Levigation and Pulverization*

THESE are properly speaking only preliminary mechanical operations for dividing and separating the particles of bodies and reducing them into very fine powder These operations can never reduce substances into their primary or elementary and ultimate particles they do

not

separate their constituent and integrant particles from each other

Brittle substances are reduced to powder by means of pestles and mortars These are of

in the plate immediately below the mortars to which they respectively belong and are made of hammered iron or brass of wood glass porcelain marble granite or agate according to

to powder by a dexterous use of the pestle

the substance to be powdered ought not to be put into the mortar at one time and we must from time to time get rid of the particles al

turning upon a flat stone In the above operations, it is often requisite to moisten the substances a little, to prevent the fine powder from flying off

There are many bodies which cannot be reduced to powder by any of the foregoing methods, such are fibrous substances, as woods, such as are tough and elastic, as the horns of animals, elastic gum, &c and the malleable metals which flatten under the pestle instead of being reduced to powder For reducing the woods to powder, rasps (Plate 1, *Fig 8*) are employed files of a finer kind are used for horn, and still finer (Plate 1 *Figs 9* and *10*) for metals

Some of the metals though not brittle enough to powder under the pestle, are too soft to be filed, as they clog the file and prevent its operation Zinc is one of these, but it may be powdered when hot in a heated iron mortar, or it may be rendered brittle, by alloying it with a small quantity of mercury One or other of these methods is used by fire-work makers for producing a blue flame by means of zinc Metals may be reduced into grains by pouring them when melted into water which serves very well when they are not wanted in fine powder

Fruits, potatoes, &c, of a pulpy and fibrous nature may be reduced to pulp by means of the grater (Plate 1, *Fig 11*)

The choice of the different substances of which these instruments are made is a matter of importance brass or copper are unfit for operations upon substances to be used as food or in pharmacy and marble or metallic instruments must not be used for acid substances hence mortars of very hard wood, and those of porcelain, granite, or glass, are of great utility in many operations

SECTION II *Of Sifting and Washing Powdered Substances*

None of the mechanical operations employed for reducing bodies to powder is capable of producing it of an equal degree of fineness throughout, the powder obtained by the longest and most accurate trituration being still an assemblage of particles of various sizes The coarser of these are removed, so as only to leave the finer and more homogeneous particles by means of sieves (Plate I, *Figs 12, 13, 14, 15*) of different finenesses, adapted to the particular purposes they are intended for all the powdered matter which is larger than the [illegible]
the [illegible]

[illegible], of or

silk gauze, and the one represented in *Fig 13* is of parchment pierced with round holes of a proper size, this latter is employed in the manufacture of gun powder When very subtile or valuable materials are to be sifted, which are easily dispersed, or when the finer parts of the powder may be hurtful, a compound sieve (*Fig 15*) is made use of, which consists of the sieve ABCD, with a lid EF, and receiver GH, these three parts are represented as joined together for use (*Fig 14*)

There is a method of procuring powders of an uniform fineness, considerably more accurate than the sieve, but it can only be used with such substances as are not acted upon by water The powdered substance is mixed and agitated with water, or other convenient fluid the liquor is allowed to settle for a few moments, and is then decanted off, the coarsest powder remains at the bottom of the vessel, and the finer passes over with the liquid By repeated decantations in this manner, various sediments are obtained of different degrees of fineness the last sediment, or that which remains longest suspended in the liquor, being the finest This process may likewise be used with advantage for separating substances of different degrees of specific gravity, though of the same fineness this last is chiefly employed in mining for separating the heavier metallic ores from the lighter earthy matters with which they are mixed

In chemical laboratories, pans and jugs of glass or earthen ware are employed for this operation sometimes, for decanting the liquor without disturbing the sediment, the glass siphon ABCHI (Plate II, *Fig 11*) is used, which may be supported by means of the perforated board DE, at the proper depth in the vessel FG, to draw off all the liquor required into the receiver LM The principles and application of this useful instrument are so well known as to need no explanation

SECTION III *Of Filtration*

A filtre is a species of very fine sieve, which is permeable to the particles of fluids, but through which the particles of the finest powdered solids are incapable of passing hence its use in separating fine powders from suspension in fluids In pharmacy, very close and fine woollen cloths are chiefly used for this operation, these are commonly formed in a conical shape (Plate II, *Fig 2*), which has the advantage of uniting all the liquor which drains through into a point A, where it may be readily collect-

For the purposes of chemistry, as it is requisite to have the filtres perfectly clean, unsized paper is substituted instead of cloth or flannel, through this substance, no solid body, however finely it be powdered, can penetrate, and fluids percolate through it with the greatest readiness As paper breaks easily when wet, various methods of supporting it are used according to circumstances When a large quantity of fluid is

means of iron hooks This cloth must be well cleaned each time it is used, or even new cloth must be employed if there is reason to suspect its being impregnated with anything which can injure the subsequent operations In ordinary operations, where moderate quantities of fluid are to be filtrated, different kinds of glass funnels are used for supporting the paper, as represented Plate II, *Figs 5*, *6*, and *7* When several filtrations must be carried on at once, the board or shelf AB, *Fig 9*, supported upon stands C and D, and pierced with round holes, is very convenient for containing the funnels

Some liquors are so thick and clammy as not to be able to penetrate through paper without some previous preparation, such as clari-

surface in the state of scum Spiritous liquors may be clarified in the same manner by means of isinglass dissolved in water, which coagulates by the action of the alcohol without the assistance of heat

As most of the acids are produced by distillation, and are consequently clear, we have rarely any occasion to filtrate them, but if, at

quartz or rock-crystal, broken in pieces and grossly powdered, answers very well a few of

means of clean washed sand, to separate its impurities

Section IV *Of Decantation*

This operation is often substituted instead of filtration for separating solid particles which are diffused through liquors These are allowed to settle in conical vessels, ABCDE (Plate II,

cantation for drawing off the clear fluid

siderable proportion of water The weight of the precipitate may indeed be ascertained by carefully weighing the filtre before and after the operation, but, when the quantity of precipitate is small, the different proportions of moisture retained by the paper, in a greater or lesser degree of exsiccation, may prove a material source of error which ought carefully to be guarded against

CHAPTER V

Of Chemical Means for Separating the Particles of Bodies from Each Other Without Decomposition, and for Uniting Them Again

I HAVE already shown that there are two methods of dividing the particles of bodies, the *mechanical* and *chemical* The former only separates a solid mass into a great number of smaller masses and for these purposes various species of forces are employed, according to cir

all these mechanical powers, we can never reduce substances into powder beyond a certain

when compared with the ultimate elementary particles of the pulverized substance

tive operations

SECTION I *Of the Solution of Salts*

In chemical language, the terms of solution and *dissolution* have long been confounded and have very improperly been indiscriminately employed for expressing both the division of the particles of a salt in a fluid, such as water, and the division of a metal in an acid A few reflections upon the effects of these two operations will suffice to show that they ought not to be confounded together In the solution of salts, the saline particles are only separated from each other, whilst neither the salt nor the water are at all decomposed, we are able to recover both the one and the other in the same quantity as *before the operation The same thing takes* place in the solution of resins in alcohol During metallic dissolutions, on the contrary, a decomposition, either of the acid or of the water which dilutes it, always takes place, the metal combines with oxygen and is changed into an oxide, and a gaseous substance is disengaged, so that in reality none of the substances employed remain, after the operation, in the same state they were in before This article is entirely confined to the consideration of solution

To understand properly what takes place during the solution of salts, it is necessary to *know that, in most of these operations, two* distinct effects are complicated together, viz, solution by water, and solution by caloric, and, as the explanation of most of the phenomena of solution depends upon the distinction of these two circumstances, I shall enlarge a little upon their nature

Nitrate of potash, usually called nitre or saltpetre, contains very little water of crystallization

being very fusible in its nature, and from its

perature Some of these, as the acetites of potash and soda, liquefy with a very moderate

loric produces exactly the same phenomena with the melting of ice, it is accomplished in each salt by a determinate degree of heat, which remains invariably the same during the whole time of the liquefaction Caloric is em*ployed and becomes fixed during the melting* of the salt, and is, on the contrary, disengaged when the salt coagulates These are general phenomena which universally occur during the

These phenomena arising from solution by caloric are always less or more conjoined with those which take place during solutions in water We cannot pour water upon a salt, on purpose to dissolve it, without employing a compound solvent, both water and caloric, hence *we may distinguish several different cases of*

will be with difficulty soluble in cold water, and considerably in hot water, such is nitrate of potash, and more especially oxygenated muriate of potash If another salt be little soluble both in water and caloric, the difference of its solubility in cold and warm water will be very inconsiderable, sulphate of lime is of this kind From these considerations, it follows that there *is a necessary relation between the following* circumstances, the solubility of a salt in cold water, its solubility in boiling water, and the degree of temperature at which the same salt liquefies by caloric, unassisted by water, and that the difference of solubility in hot and cold water is so much greater in proportion to its ready solution in caloric, or in proportion to its susceptibility of liquefying in a low degree of temperature

an approximation towards a particular theory The means of completing this part of chemical science is extremely simple, we have only to ascertain how much of each salt is dissolved by a certain quantity of water at different degrees of temperature, and as, by the experiments published by M de Laplace and me, the quantity of caloric contained in a pound of water at each degree of the thermometer is accurately known, it will be very easy to determine, by simple experiments, the proportion of water and caloric required for solution by each salt, what quantity of caloric is absorbed by each at the moment of liquefaction, and how much is disengaged at the moment of crystallization

Hence the reason why salts are more rapidly soluble in hot than in cold water is perfectly evident In all solutions of salts caloric is employed, when that is furnished intermediately from the surrounding bodies, *it can only arrive* slowly to the salt, whereas this is greatly accelerated when the requisite caloric exists ready combined with the water of solution

In general the specific gravity of water is augmented by holding salts in solution but there are some exceptions to the rule Some time hence, the quantities of radical, of oxygen, and of base, which constitute each neutral salt, the quantity of water and caloric necessary for solution the increased specific gravity communicated to water, and the figure of the elementary particles of the crystals, will all be accurately known From these all the circumstances and phenomena of crystallization will be explained, and by these means this part of chemistry will be completed M Seguin has formed the plan of a thorough investigation of this kind, which he is extremely capable of executing

The solution of salts in water requires no particular apparatus small glass phials of different sizes (Plate II, *Figs 16* and *17*), pans of earthern ware A (*Figs 1* and *2*), long necked matrasses (*Fig 14*), and pans or basins of copper or of silver (*Figs 13* and *15*) answer very well for these operations

SECTION II *Of Lixiviation*

This is an operation used in chemistry and manufactures for separating substances which are soluble in water from such as are insoluble The large vat or tub (Plate II *Fig 12*), having a hole D near its bottom containing a wooden spiget and faucet or metallic stop-cock DE, is generally used for this purpose A thin stratum of straw is placed at the bottom of the tub

the water charged with salt necessarily adheres to the straw and insoluble matters several fresh quantities of water are poured on The straw

where it is poured on, through which it might escape without acting upon the whole mass

This operation is less or more imitated in chemical experiments, but as in these, *especially with analytical views, greater exactness is* required, particular precautions must be employed, so as not to leave any saline or soluble part in the residuum More water must be employed than in ordinary lixiviations, and the substances ought to be previously stirred up in the water before the clear liquor is drawn off, otherwise the whole mass might not be equally lixiviated, and some parts might even escape altogether from the action of the water We must likewise employ fresh portions of water in considerable quantity, until it comes off entirely free from salt which we may ascertain by means of the hydrometer formerly described

In experiments with small quantities, this operation is conveniently performed in jugs or

en frame (Plate II Figs 3 and 4) and in operations in the large way, the tub already mentioned must be used

SECTION III *Of Evaporation*

This operation is used for separating two substances from each *other, of which one at* least must be fluid and whose degrees of volatility are considerably different By this means we obtain a salt, which has been dissolved in

process, hence we may consider this gradual evaporation as a compound solution made part-

and in it the evaporation produced by the action of the air is exceedingly inconsiderable in comparison with that which is occasioned by caloric This latter species may be termed *vaporization* rather than *evaporation* This process is not accelerated in proportion to the extent of evaporating surface, but in proportion to the quantities of caloric which combine with the fluid Too free a current of cold air is often hurtful to this process, as it tends to carry off caloric from the water and consequently retards its conversion into vapour Hence there is no inconvenience produced by covering, in a certain degree, the vessels in which liquids are evaporated by continual boiling, provided the covering body be of such a nature as does not strongly draw off the caloric, or, to use an expression of Dr Franklin's, provided it be a bad conductor of heat In this case, the vapours escape through such opening as is left, and at least as much is evaporated, frequently more than when free access is allowed to the external air

As during evaporation the fluid carried off by caloric is entirely lost, being sacrificed for the sake of the fixed substances with which it was combined, this process is only employed where the fluid is of small value, as water, for instance But, when the fluid is of more consequence, we have recourse to distillation, in which process we preserve both the fixed substance and the volatile fluid The vessels employed for evaporation are basins or pans of copper, silver, or lead (Plate II, *Figs 13* and *15*), or capsules of glass, porcelain, or stone ware (Plate II, A, *Figs 1* and *2*, Plate III, *Figs 3* and *4*) The best utensils for this purpose are made of the bottoms of glass retorts and matrasses, as their equal thinness renders them more fit than any other kind of glass vessel for bearing a brisk fire and sudden alterations of heat and cold without breaking

As the method of cutting these glass vessels is nowhere described in books, I shall here give a description of it, that they may be made by chemists for themselves out of spoiled retorts, matrasses, and recipients, at a much cheaper rate than any which can be procured from glass manufacturers The instrument (Plate III, *Fig 5*), consisting of an iron ring AC, fixed to the rod AB, having a wooden handle D, is employed as follows Make the ring red hot in the fire, and put it upon the matrass G (*Fig 6*), which is to be cut, when the glass is sufficiently heated, throw on a little cold water, and it will generally break exactly at the circular line heated by the ring

Small flasks or phials of thin glass are exceeding good vessels for evaporating small quantities of fluid they are very cheap, and stand the fire remarkably One or more of these may be placed upon a second grate above the furnace (Plate III, *Fig 2*), where they will only experience a gentle heat. By this means a great number of experiments may be carried on at one time A glass retort, placed in a sand-bath, and covered with a dome of baked earth (Plate III, *Fig 1*), answers pretty well for evaporations, but in this way it is always considerably slower, and is even liable to accidents; as the sand heats unequally, and the glass cannot dilate in the same unequal manner, the retort is very liable to break Sometimes the sand serves exactly the office of the iron ring formerly mentioned, for, if a single drop of vapour, condensed into liquid, happens to fall upon the heated part of the vessel, it breaks circularly at that place When a very intense fire is necessary, earthen crucibles may be used, but we generally use the word *evaporation* to express what is produced by the temperature of boiling water or not much higher

SECTION IV Of Crystallization

In this process the integrant parts of a solid body, separated from each other by the intervention of a fluid, are made to exert the mutual attraction of aggregation, so as to coalesce and reproduce a solid mass When the particles of a body are only separated by caloric, and the substance is thereby retained in the liquid state, all that is necessary for making it crystallize is to remove a part of the caloric which is lodged between its particles, or, in other words, to cool it. If this refrigeration be slow, and the body be at the same time left at rest, its particles assume a regular arrangement, and crystallization, properly so called, takes place but, if the refrigeration is made rapidly, or if the liquor be agitated at the moment of its passage to the concrete state, the crystallization is irregular and confused

The same phenomena occur with watery solutions, or rather in those made partly in water and partly by caloric So long as there [illegible] s a sufficiency of water [illegible]

part [illegible]

[illegible] for each other [illegible] superior to the power which keeps them asunder, the salt recovers its concrete

form and the crystals produced are the more regular in proportion as the evaporation has been slower and more tranquilly performed

All the phenomena we formerly mentioned as taking place during the solution of salts oc

tion by the compound action of water and caloric Hence to cause salts to crystallize which readily liquefy by means of caloric it is not sufficient to carry off the water which held them in solution but the caloric united to them must likewise be removed Nitrate of potash oxygenated muriate of potash alum sulphate of soda, &c , are examples of this circumstance as, to make these salts crystallize refrigeration must be added to evaporation Such salts on the contrary, as require little caloric for being kept in solution and which, from that circumstance, are nearly equally soluble in cold and warm water, are crystallizable by simply carrying off the water which holds them in solution, and even recover their solid state in boiling water such are sulphate of lime muriate of potash and of soda, and several others

petre, and other salts, by further evaporation,

The deliquescent earthy salts which do not contain the nitric acid are rejected in this manufacture, but those which consist of that acid neutralized by an earthy base are dissolved in water the earth is precipitated by means of potash and allowed to subside the clear liquor is then decanted evaporated and allowed to crystallize The above management for refin

different solubility of each in hot and cold water If to these we add the property which some salts possess of being soluble in alcohol or in a mixture of alcohol and water we have many resources for separating salts from each other by means of crystallization though it must be allowed that it is extremely difficult to render

our experiments are composed of congeries of minute particles, which, though perfectly equal

class of salts the principles he has particularly applied to some crystallized stones

SECTION V *Of Simple Distillation*

As distillation has two distinct objects to accomplish, it is divisible into simple and compound, and, in this section, I mean to confine myself entirely to the former When two bodies, of which one is more volatile than the other, or has more affinity to caloric, are submitted to distillation, our intention is to separate them from each other The more volatile substance assumes the form of gas, and is afterwards condensed by refrigeration in proper vessels In this case distillation like evaporation, becomes a species of mechanical operation, which separates two substances from each other without decomposing or altering the nature of either In evaporation, our only object is to preserve the fixed body, without paying any regard to the volatile matter whereas, in distillation, our principal attention is generally paid to the volatile substance, unless when we intend to preserve both the one and the other Hence, simple distillation is nothing more than evaporation produced in close vessels

The most simple distilling vessel is a species of bottle or matrass A (Plate III Fig 5), which has been bent from its original form BC to BD, and which is then called a retort when used, it is placed either in a reverberatory furnace (Plate XIII, Fig 2) or in a sand bath under a dome of baked earth (Plate III, Fig 1) To receive and condense the products, we adapt a recipient E (Plate III Fig 9), which is luted to the retort Sometimes more especially in pharmaceutical operations, the glass or stone ware cucurbit, A, with its capital B (Plate III, Fig 12) or the glass alembic and capital (Fig 13) of one piece is employed This latter is managed by means of a tubulated opening T, fitted with a ground stopper of crystal the capital, both of the cucurbit and alembic, has a furrow or trench, rr, intended for conveying the condensed liquor into the beak RS by which it runs out As, in almost all distillations, expansive vapours are produced, which might burst the vessels employed, we are under the necessity of having a small hole T (Fig 9) in the balloon or recipient, through which these may find vent, hence in this way of distilling, all the products which are permanently aeriform are entirely lost, and even such as with difficulty lose that state have not sufficient space to condense in the balloon This apparatus is not, therefore, proper for experiments of investigation, and can only be admitted in the ordinary operations of the laboratory or in pharmacy

In the article appropriated for compound distillation, I shall explain the various methods which have been contrived for preserving the whole products from bodies in this process

As glass or earthen vessels are very brittle, and do not readily bear sudden alterations of heat and cold, every well regulated laboratory ought to have one or more alembics of metal for distilling water, spiritous liquors, essential oils, &c This apparatus consists of a cucurbit and capital of tinned copper or brass (Plate III, Figs 15 and 16), which, when judged proper, may be placed in the water bath D (Fig 17) In distillations, especially of spiritous liquors, the capital must be furnished with a refrigeratory, SS (Fig 16), kept continually filled with cold water, when the water becomes heated, it is let off by the stop cock, R, and renewed with a fresh supply of cold water As the fluid distilled is converted into gas by means of caloric furnished by the fire of the furnace, it is evident that it could not condense, and, consequently, that no distillation, properly speaking could take place unless it is made to deposit in the capital all the caloric it received in the cucurbit, with this view, the sides of the capital must always be preserved at a lower temperature than is necessary for keeping the distilling substance in the state of gas and the water in the refrigeratory is intended for this purpose Water is converted into gas by the temperature of 80° (212°), alcohol by 67° (182 75°), ether by 32° (104°) hence these substances cannot be distilled, or rather, they will fly off in the state of gas, unless the temperature of the refrigeratory be kept under these respective degrees

In the distillation of spiritous and other expansive liquors the above described refrigeratory is not sufficient for condensing all the vapours which arise in this case, therefore, instead of receiving the distilled liquor immediately from the beak, TU, of the capital into a recipient, a worm is interposed between them This instrument is represented Plate III, Fig 18, contained in a worm tub of tinned copper, it consists of a metallic tube bent into a considerable number of spiral revolutions The vessel which contains the worm is kept full of cold water, which is renewed as it grows warm This contrivance is employed in all distilleries of spirits, without the intervention of a capital and refrigeratory, properly so called The one represented in the plate is furnished with two worms, one of them being particularly appropriated to distillations of odoriferous substances

In some simple distillations it is necessary to interpose an adopter between the retort and receiver as shown (Plate III *Fig 11*) This may serve two different purposes either to separate two products of different degrees of volatility or to remove the receiver to a greater distance from the furnace that it may be less heated But these and several other more complicated instruments of ancient contrivance are far from producing the accuracy *requisite in modern chemistry as will be* readily perceived when I come to treat of compound distillation

SECTION VI *Of Sublimation*

This term is applied to the distillation of substances which condense in a concrete or solid form such as the sublimation of sulphur and of muriate of ammonia or sal ammonia These operations may be conveniently performed in the ordinary distilling vessels already described though in the sublimation of sulphur a species of vessels named *alludels* have been usually employed These are vessels of stone or porcelain ware which adjust to each other over a cucurbit containing the sulphur to be sublimed One of the best subliming vessels for substances which are not very volatile is a flask or phial of glass sunk about two thirds into a sand bath but in this way we are apt to lose a part of the products When these are wished to be entirely preserved we must have recourse to the pneumato-chemical distilling apparatus to be described in the following chapter

CHAPTER VI

Of Pneumato-chemical Distillations Metallic Dissolutions and Some Other Operations Which Require Very Complicated Instruments

SECTION I *Of Compound and Pneumato-chemical Distillations*

stances submitted to its action and becomes one of the most complicated operations in

out in the refrigeratory or in the worm and the substance again recovers its liquid or solid form but the substances submitted to compound distillation are absolutely decompounded one part as for instance the charcoal they contain remains fixed in the retort and all the rest of the elements are reduced to gases of different kinds Some of these are susceptible of being condensed and of recovering their solid or liquid forms whilst others are permanently *aeriform one part of these are absorbible by*

recourse for this purpose to methods of a more complicated nature

The apparatus I am about to describe is calculated for the most complicated distillations and may be simplified according to circum

is adjusted which at its other extremity *g* is plunged into the liquor contained in the bottle L with three necks *xxx* Three other similar

must be accurately ascertained Every thing

together

the recipient GC, whilst the gases, which are not susceptible of condensation by cold, will *pass on by the tubes, and boil up through the* liquors in the several bottles Such as are absorbable by water will remain in the first bottle, and those which caustic alkali can absorb will remain in the others, whilst such gases as are not susceptible of absorption, either by water or alkalies, will escape by the *tube RM, at the end of which they may be* received into jars in a pneumato-chemical apparatus The charcoal and fixed earth, &c which form the substance or residuum, once called *caput mortuum*, remain behind in the retort

In this manner of operating, we have always a very material proof of the accuracy of the analysis, as the whole weights of the products taken together, after the process is finished, must be exactly equal to the weight of the original substance submitted to distillation Hence, for instance, if we have operated upon eight ounces of starch or gum arabic, the weight of the charry residuum in the retort, together with that of all the products gathered in its neck and the balloon, and of all the gas received into the jars by the tube RM added to the additional weight acquired by the bottles, must, when taken together, be exactly eight ounces If the product be less or more, it proceeds from error, and the *experiment must be repeated until a* satisfactory result be procured, which ought not to differ more than six or eight grains in the pound from the weight of the substance submitted to experiment

In experiments of this kind, I for a long time met with an almost insurmountable difficulty, which must at last have obliged me to desist altogether but for a very simple method of avoiding it, pointed out to me by M Hassenfratz The smallest diminution in the heat of the furnace, and many other circumstances inseparable from this kind of experiments, cause frequent reabsorptions of gas, the water in the cistern of the pneumato-chemical apparatus rushes into the last bottle through the tube RM, the same circumstance happens from one bottle into another, and the fluid is often forced even into the recipient C This accident [illegible] vented by using bottl[illegible] [illegible] , st, st, st, [illegible] ave its lower extremity t immersed in the liquor If any absorption takes place, either in the retort or in any of the bottles, a sufficient quantity of external air enters, by means of these tubes, to fill up the void and we get rid of the inconvenience at the price *of having a small mixture of common air with* the products of the experiment, which is thereby prevented from failing altogether Though these tubes admit the external air, they cannot permit any of the gaseous substances to escape as they are always shut below by the water of the bottles

It is evident that, in *the* course *of* experiments with this apparatus the liquor of the bottles must rise in these tubes in proportion to the pressure sustained by the gas or air contained in the bottles, and this pressure is determined by the height and gravity of the column of fluid contained in all the subsequent bottles If we suppose *that each bottle contains* three inches of fluid, and that there are three inches of water in the cistern of the connected apparatus above the orifice of the tube RM, and allowing the gravity of the fluids to be only equal to that of water, it follows that the air in the first bottle must sustain a pressure equal to twelve inches of water, the water *must* therefore rise twelve inches in the tube S, connected with the first bottle, nine inches in that belonging to the second, six inches in the third, and three in the last wherefore these tubes must be made somewhat more than twelve, nine, six and three inches long respectively, al*lowance being made for oscillatory motions,* which often take place in the liquids It is sometimes necessary to introduce a similar tube between the retort and recipient and, as the tube is not immersed in fluid at its lower extremity until some has collected in the progress of the distillation, its upper end must be shut at first with a little lute, so as to be opened according to necessity or after there is sufficient liquid in the recipient to secure its lower extremity

This apparatus cannot be used in very accurate experiments, when the substances intended to be operated upon have a very rapid action upon each other or when one of them can only be introduced in small successive portions, as in such as produce violent effervescence when mixed together In such cases, we employ a tubulated *retort A (Plate VII, Fig 1), into* which one of the substances is intr[illegible] ferring alway[illegible] be treat[illegible] retort a [illegible], terminating at its upper extremity B in a funnel, and at its other end A in a capillary opening The fluid material *of the experiment is poured into the retort by*

means of this funnel, which must be made of such a length, from B to C, that the column of liquid introduced may counterbalance the resistance produced by the liquors contained in all the bottles (Plate IV, *Fig 1*)

Those who have not been accustomed to use the above described distilling apparatus may perhaps be startled at the great number of openings which require luting, and the time necessary for making all the previous preparations in experiments of this kind It is very true that, if we take into account all the necessary weighings of materials and products, both before and after the experiments, these preparatory and succeeding steps require much more time and attention than the experiment *itself* But, when the experiment succeeds properly, we are well rewarded for all the time and trouble bestowed as by one process carried on in this accurate manner much more just and extensive knowledge is acquired of the nature of the vegetable or animal substance thus submitted to investigation than by many weeks assiduous labour in the ordinary method of proceeding.

When in want of bottles with three orifices, those with two may be used, it is even possible to introduce all the three tubes at one opening, so as to employ ordinary wide-mouthed bottles provided the opening be sufficiently large In this case we must carefully fit the bottles with corks very accurately cut and boiled in a mixture of oil, wax, and turpentine These corks are pierced with the necessary holes for receiving the tubes by means of a round file, as in Plate IV, *Fig 8*

SECTION II *Of Metallic Dissolutions*

I have already pointed out the difference between solution of salts in water and metallic dissolutions The former requires no particular vessels, whereas the latter requires very complicated vessels of late invention, that we may not lose any of the products of the experiment, and may thereby procure truly conclusive results of the phenomena which occur The metals, in general dissolve in acids with effervescence, which is only a motion excited in the

at the surface of the liquid

M Cavendish and Dr Priestley were the first inventors of a proper apparatus for collecting these elastic fluids That of Dr Priestley is extremely simple and consists of a bottle A (Plate VII, *Fig 2*), with its cork B, through which passes the bent glass tube BC, which is engaged under a jar filled with water in the pneumato-chemical apparatus, or simply in a basin full of water The metal is first introduced into the bottle, the acid is then poured over it, and the bottle is instantly closed with its cork and tube as represented in the plate But this apparatus has its inconveniences When the acid is much concentrated, or the metal much divided, the effervescence begins before

rigorous exactness In the next place, when we are obliged to employ heat, or when heat is produced by the process a part of the acid distills and mixes with the water of the pneumato-chemical apparatus, by which means we are deceived in our calculation of the quantity of acid decomposed Besides these, the water in the cistern of the apparatus absorbs all the gas produced which is susceptible of absorption and renders it impossible to collect these without loss

To remedy these inconveniences, I at first used a bottle with two necks (Plate VII, *Fig 3*), into one of which the glass funnel BC is luted so as to prevent any air escaping, a glass rod

Another method has been since employed, which serves the same purpose, and is prefer able to the last described in some instances

pose of an accurate cork

To prevent any distillation of acid, especially in dissolutions accompanied with heat, this tube is adapted to the retort A (Plate VII, *Fig 1*), and a small tubulated recipient, M.

necked bottle L, half filled with a solution of

amined If one bottle of alkaline solution be not thought sufficient, two, three, or more, may be added

SECTION III *Apparatus Necessary in Experiments upon Vinous and Putrefactive Fermentations*

For these operations a peculiar apparatus, especially intended for this kind of experiment, is requisite The one I am about to describe is finally adopted as the best calculated for the purpose, after numerous corrections and im-

tube *cd*, furnished with a stop-cock *e* To this tube is joined the glass recipient B, having three openings, one of which communicates with the bottle C placed below it To the posterior opening of this recipient is fitted a glass tube *ghi* cemented at *g* and *i* to collets of brass, and intended to contain a very deliquescent concrete neutral salt, such as nitrate or muriate of lime, acetite of potash &c This tube communicates with two bottles D and E, filled to *x* and *y* with a solution of caustic potash

All the parts of this machine are joined together by accurate screws, and the touching parts have greased leather interposed, to prevent any passage of air Each piece is likewise furnished with two stop-cocks, by which its two extremities may be closed, so that we can weigh each separately at any period of the operation

quantity of froth is produced, ...

fills the neck of the matrass, but passes into the recipient, and from thence runs down into

and connected bottle are made of considerable capacity

In the vinous fermentation, only carbonic acid gas is disengaged, carrying with it a small proportion of water in solution A great part of this water is deposited in passing through the tube *ghi*, which is filled with a deliquescent

this first bottle is secured by the solution in the second bottle E, so that nothing, in general, passes into the jar F, except the common air contained in the vessels at the commencement of the experiment

jar F, and, as this disengagement is very rapid, especially in summer the jar must be frequently changed These putrefactive fermentations require constant attendance from the above circumstance, whereas the vinous fermentation hardly needs any By means of this apparatus we can ascertain, with great precision, the weights of the substances submitted to fermentation, and of the liquid and aeriform products which are disengaged What has been already said in Part I, Chapter XIII, upon the products of the vinous fermentation, may be consulted

SECTION IV *Apparatus for the Decomposition of Water*

Having already given an account, in the first part of this work, of the experiments relative to the decomposition of water, I shall avoid any unnecessary repetitions and only give a few summary observations upon the subject in this section The principal substances which have the power of decomposing water are iron and charcoal, for which purpose, they require

... black

gages, mixed with the hydrogen gas and this

latter is commonly carbonated, or holds charcoal in solution

A musket barrel, without its breach pin, answers exceedingly well for the decomposition of water by means of iron, and one should be chosen of considerable length and pretty strong When *too short, so as to run the risk of heating*

upon the furnace VVXX The lower extremity F is luted to a worm SS which is connected with the tubulated bottle H, in which any water distilled without decomposition, during the operation, collects, and the disengaged gas is carried by the tube KK to jars in a pneumato-

verted into steam, and the experiment proceeds in the same manner as if it were furnished in vapours from the retort

In the experiment made by M Meusnier and me before a committee of the Academy, we used every precaution to obtain the greatest possible precision in the result of our experiment having even exhausted all the vessels employed before we began, so that the hydrogen gas obtained might be free from any mixture of azotic gas The results of that experiment will hereafter be given at large in a particular *Mémoire*

In numerous experiments, we are obliged to

posing alcohol, which resolves into charcoal, carbonic acid gas, and hydrogen gas it may likewise be used with the same advantage for decomposing water by means of charcoal. and in a great number of experiments nature.

CHAPTER VII

Of the Composition and Use of Lutes

THE necessity of properly securing the junctures of chemical vessels to prevent the escape of any of the products of experiments must be *sufficiently apparent for this purpose lutes are* employed which ought to be of such a nature as to be equally impenetrable to the most subtile substances, as glass itself through which only caloric can escape

This first object of lutes is very well accomplished by bees wax, melted with about an

able, by adding different kinds of resinous matters Though this species of lute answers extremely well for retaining gases and vapours there are many chemical experiments which

and escape

Take very pure and dry unbaked clay reduced to a very fine powder put this into a brass mortar and beat it for several hours with a heavy

dom used

The above fat lute is capable of sustaining a

liquor in the course of an experiment gets

ence which attends the use of fat lute and perhaps the only one it is subject to As it is apt to [illegible] heat we must surround all the junc- [illegible] applied over the [illegible] round both above and [illegible] bladder, and consequently the lute below, [illegible] be farther secured by a number of turns of packthread all over it. By these precautions, we are free from every danger of accident and the junctures secured in this manner may be considered, in experiments, as hermetically sealed

It frequently happens that the figure of the junctures prevents the application of ligatures, which is the case with the three-necked bottles formerly described, and it even requires great address to apply the twine without shaking the apparatus so that, where a number of junctures require luting, we are apt to displace several while securing one In these cases, we may substitute slips of linen, spread with white of egg and lime mixed together, instead of the wet bladder These are applied while still moist, and very speedily dry and acquire considerable hardness Strong glue dissolved in water may answer instead of white of egg These fillets are usefully applied likewise over junctures luted together with wax and rosin

Before applying a lute, all the junctures of the vessels must be accurately and firmly fitted to each other, so as not to admit of being moved If the beak of a retort is to be luted to the neck of a recipient, they ought to fit pretty accurately, otherwise we must fix them, by introducing short pieces of soft wood or of cork If the disproportion between the two be very considerable, we must employ a cork which fits the neck of the recipient, having a circular hole of proper dimensions to admit the beak of the retort The same precaution is necessary in adapting bent tubes to the necks of bottles in the apparatus represented Plate IV, Fig 1, and others of a similar nature Each mouth of each bottle must be fitted with a cork, having a hole made with a round file of a proper size for containing the tube And, when one mouth is intended to admit two or more tubes, which frequently happens when we have not a sufficient number of bottles with two or three necks, we must use a cork with two or three holes (Plate IV, Fig 8)

When the whole apparatus is thus solidly joined, so that no part can play upon another, we begin to lute The lute is softened by kneading and rolling it between the fingers, with the assistance of heat if necessary It is rolled into little cylindrical pieces and applied to the junctures, taking great care to make it apply close and adhere firmly in every part, a second roll is applied over the first, so as to pass it on each side, and so on till each juncture be sufficiently covered, after this, the slips of bladder, or of linen, as above directed, must be carefully applied over all Though this operation may appear extremely simple, yet it requires peculiar delicacy and management, great care must be taken not to disturb one juncture whilst luting another, and more especially when applying the fillets and ligatures

Before beginning any experiment, the closeness of the luting ought always to be previously tried, either by slightly heating the retort A (Plate IV, Fig 1), or by blowing in a little air by some of the perpendicular tubes S s s s, the alteration of pressure causes a change in the level of the liquid in these tubes If the apparatus be accurately luted, this alteration of level will be permanent, whereas, if there be the smallest opening in any of the junctures, the liquid will very soon recover its former level It must always be remembered that the whole success of experiments in modern chemistry depends upon the exactness of this operation, which therefore requires the utmost patience and most attentive accuracy

It would be of infinite service to enable chemists, especially those who are engaged in pneumatic processes, to dispense with the use of lutes, or at least to diminish the number necessary in complicated instruments I once thought of having my apparatus constructed so as to unite in all its parts by fitting with emery, in the way of bottles with crystal stoppers, but the execution of this plan was extremely difficult I have since thought it preferable to substitute columns of a few lines of mercury in place of lutes, and have got an apparatus constructed upon this principle, which appears capable of very convenient application in a great number of circumstances.

It consists of a double necked bottle A (Plate XII, Fig 12), the interior neck bc communicates with the inside of the bottle, and the exterior neck or rim de leaves an interval between the two necks, forming a deep gutter intended to contain the mercury The cap or lid of glass B enters this gutter and is properly fitted to it, having notches in its lower edge for the passage of the tubes which convey the gas These tubes, instead of entering directly into the bottles as in the ordinary apparatus have a double bend for making them enter the gutter, as repre-

disposed in their proper places and the cap firmly fitted on, the gutter is filled with mercury, by which means the bottle is completely excluded from any communication, excepting through the tubes This apparatus may be very convenient in many operations in which the substances employed have no action upon mercury Plate xii, *Fig 14*, represents an apparatus upon this principle properly fitted together

M Seguin to whose active and intelligent assistance I have been very frequently much indebted has bespoken for me at the glass houses, some retorts hermetically united to their recipients by which luting will be altogether unnecessary

CHAPTER VIII

Of Operations upon Combustion and Deflagration

SECTION I *Of Combustion in General*

COMBUSTION, according to what has been already said in the first part of this work is the decomposition of oxygen gas produced by a combustible body The oxygen which forms

expression can only take place at a certain degree of temperature, which is different for each combustible substance hence the necessity of giving a first motion or beginning to every combustion by the approach of a heated body This necessity of heating any body we mean to burn depends upon certain considerations

spontaneous combustions or oxygenations possible in the ordinary degrees of temperature had taken place Hence, no new combustions

matter by example let us suppose the usual temperature of the earth a little changed, and that it is raised only to the degree of boiling water it is evident that in this case, phosphorus, which is combustible in a considerably lower degree of temperature, would no longer exist in nature in its pure and simple state but would always be procured in its acid or oxygenated state and its radical would become one *of the substances unknown to chemistry* By gradually increasing the temperature of the earth the same circumstance would successively happen to all the bodies capable of combustion, and at last, every possible combustion having taken place, there would no longer exist any combustible body whatever, as every substance susceptible of that operation would be oxygenated and consequently incombustible

composition of the oxygen gas keeps up the temperature necessary *for continuing combus tion* When this is not the case that is when the disengaged caloric is insufficient for keeping up the necessary temperature the combus-

originally in the body, is brought into action, oxygen is added to the substance submitted to the operation, and caloric is disengaged

The necessity of employing oxygen in the state of gas in all experiments with combustion, and the rigorous determination of the quantities employed, render this kind of operations peculiarly troublesome As almost all the products of combustion are disengaged in the state of gas, it is still more difficult to retain them than even those furnished during compound distillation, hence this precaution was entirely neglected by the ancient chemists, and this set of experiments exclusively belong to modern chemistry

Having thus pointed out, in a general way, the objects to be had in view in experiments upon combustion, I proceed in the following sections of this chapter, to describe the different instruments I have used with this view The following arrangement is formed, not upon the nature of the combustible bodies, but upon that of the instruments necessary for combustion

SECTION II *Of the Combustion of Phosphorus*

begins to flow out below, the jar, A, is carried to the mercury apparatus (Plate IV, *Fig 3*) We then dry the surface of the mercury, both within and without the jar, by means of blotting paper, taking care to keep the paper for some time entirely immersed in the mercury before it is introduced under the jar, lest we let in any common air, which sticks very obstinately to the surface of the paper The body to be submitted to combustion being first very

sensible degree

When the cup, D, is introduced under the jar, we suck out a part of the oxygen gas, so as to raise the mercury to EF, as formerly directed, Part I, Chapter V, otherwise, when the combustible body is set on fire, the gas becoming dilated would be in part forced out, and we should no longer be able to make any accurate calculation of the quantities before and after the experiment A very convenient mode of drawing out the air is by means of an air-pump syringe adapted to the siphon, GHI, by which the mercury may be raised to any degree under twenty-eight inches Very inflammable bodies as phosphorus, are set on fire by means of the crooked iron wire MN (Plate IV, *Fig 16*) made red hot and passed quickly through the mercury Such as are less easily set on fire have a small portion of tinder, upon which a minute particle of phosphorus is fixed, laid upon them before using the red hot iron

In the first moment of combustion the air, being heated, rarifies, and the mercury descends, but when as in combustions of phosphorus and iron, no elastic fluid is formed, absorption becomes presently very sensible, and the mercury rises high into the jar Great attention must be used not to burn too large a quantity of any substance in a given quantity of gas, otherwise towards the end of the experiment the cup would approach so near the top of the jar as to endanger breaking it by the great heat produced and the sudden refrigeration from the cold mercury For the methods of measuring the volume of the gases, and for correcting the measures according to the height of the barometer and thermometer, &c, see Chapter II, Sections V and VI of this part

The above process answers very well for burning all the concrete substances, and even for the fixed oils These last are burnt in lamps under the jar and are readily set on fire by means of tinder, phosphorus, and hot iron But it is dangerous for substances susceptible of

and animal matters which contain an excess of hydrogen, this apparatus can neither collect it nor determine its quantity The experiment with phosphorus is even incomplete in this way, as it is impossible to demonstrate that the weight of the phosphoric acid produced is equal to the sum of the weights of the phosphorus burnt and oxygen gas absorbed during the process I have been, therefore, obliged to vary the instruments according to circumstances, and to employ several of different kinds, which I shall describe in their order, beginning with that used for burning phosphorus

Take a large balloon A (Plate IV, *Fig 4*) of crystal or white glass, with an opening EF, about two inches and a half or three inches diameter, to which a cap of brass is accurately

on the cap with fat lute and allow it to dry for some days and weigh the whole accurately after this exhaust the balloon by means of an air pump connected with the tube *xxx*, and fill it with oxygen gas by the tube *yyy*, from the gazometer (Plate VIII, *Fig 1*) described Chapter II, Section II, of this part The phosphorus is then set on fire by means of a burning glass and is allowed to burn till the cloud of concrete phosphoric acid stops the combustion, oxygen gas being continually supplied

for greater accuracy, to examine the air or gas contained in the balloon after combustion, as it may happen to be somewhat heavier or lighter than common air and this difference of weight must be taken into account in the calculations upon the results of the experiment

SECTION III *Of the Combustion of Charcoal*

charcoal is burnt, the grate, *de*, and the ash-hole, F, the tube, GH, in the middle of the

gazometer, the hydrogen gas, or air, intended for supporting the combustion, is conveyed into the ash-hole, F, whence it is forced, by the

gas of the air is not altered at all Hence, after the combustion of charcoal in atmospheric air, a mixture of carbonic acid gas and azotic gas must remain to allow this mixture to pass off, the tube *op* is adapted to the chimney, GH, by means of a screw at G, and conveys the gas into bottles half filled with solution of caustic potash The carbonic acid gas is absorbed by the alkali, and the azotic gas is conveyed into a second gazometer where its quantity is ascertained

The weight of the furnace ABC, is first accurately determined then introduce the tube

again, to know the exact quantity of charcoal submitted to experiment The furnace is now put in its place, the tube, *lmn*, is screwed to that which communicates with the gazometer, and the tube, *op*, to that which communicates with the bottles of alkaline solution Every

instantly withdrawn, and the tube, *op* is

in the cistern [illegible] (Plate XII, *Fig 11*), to which ice may be added to moderate the heat, if necessary, though the heat is by no means very considerable, as there is no air but what comes from the gazometer, and no more of the charcoal burns at one time than what is immediately over the grate

As one piece of charcoal is consumed another falls down into its place, in

originally in the body, is brought into action,

state of gas in all experiments with combustion, and the rigorous determination of the quantities employed, render this kind of operations peculiarly troublesome As almost all the products of combustion are disengaged in the state of gas, it is still more difficult to retain them than even those furnished during compound distillation, hence this precaution was entirely neglected by the ancient chemists, and this set of experiments exclusively belong to modern chemistry

Having thus pointed out, in a general way, the objects to be had in view in experiments upon combustion, I proceed in the following sections of this chapter, to describe the different instruments I have used with this view The following arrangement is formed, not upon the nature of the combustible bodies, but upon that of the instruments necessary for combustion

SECTION II *Of the Combustion of Phosphorus*

begins to flow out below, the jar, A, is carried to the mercury apparatus (Plate IV, *Fig 3*) We then dry the surface of the mercury, both within and without the jar, by means of blotting-paper, taking care to keep the paper for some time entirely immersed in the mercury before it is introduced under the jar, lest we let in any common air, which sticks very obstinately to the surface of the paper The body to be submitted to combustion, being first very

is passed through the mercury into the jar,

progress or accuracy of the experiment in any sensible degree

When the cup, D, is introduced under the jar, we suck out a part of the oxygen gas, so as to raise the mercury to EF, as formerly directed, Part I, Chapter V, otherwise, when the combustible body is set on fire, the gas becoming dilated would be in part forced out, and we should no longer be able to make any accurate calculation of the quantities before and after the experiment A very convenient mode of drawing out the air is by means of an air pump syringe adapted to the siphon, GHI, by which the mercury may be raised to any degree under twenty-eight inches Very inflammable bodies, as phosphorus, are set on fire by means of the crooked iron wire MN (Plate IV, *Fig 16*) made red hot and passed quickly through the mercury Such as are less easily set on fire have a small portion of tinder, upon which a minute particle of phosphorus is fixed, laid upon them *before using the red hot iron*

In the first moment of combustion the air, being heated, rarifies, and the mercury descends, but when, as in combustions of phosphorus and iron, no elastic fluid is formed, absorption becomes presently very sensible, and the mercury rises high into the jar Great attention must be used not to burn too large a quantity of any substance in a given quantity

of measuring the volume of the gases, and for

burning all the concrete substances, and even for the fixed oils These last are burnt in lamps under the jar and are readily set on fire by means of tinder, phosphorus, and hot iron But it is dangerous for substances susceptible of

wise formed in all experiments upon veg-

kind more readily followed, it is represented completely connected together for use in Plate XI The gazometer P furnishes air for the combustion by the tube and stop cock 1, 2, the tube 2 3, communicates with a second gazometer, which is filled whilst the first one is emptying during the process, that there may be no interruption to the combustion 4, 5, is a tube

[illegible]

it is easy to determine the quantity of water absorbed by them from the air From this deliquescent tube the air is conducted through the pipe 5 6, 7, 8, 9, 10, to the lamp 11, where it spreads on both sides of the wick, as before described, and feeds the flame One part of this air, which serves to keep up the combustion of the oil, forms carbonic acid gas and water by oxygenating its elements Part of this water condenses upon the sides of the pitcher A, and another part is held in solution in the air by means of caloric furnished by the combustion This air is forced by the compression of the gazometer to pass through the tube 12, 13, 14, 15, into the bottle 16, and the worm 17, 18, where the water is fully condensed from the refrigeration of the air and, if any water still remains in solution, it is absorbed by deliques-

[illegible]

resented two of these in the figure, but nine at least are requisite, and the last of the series may be half filled with lime-water, which is the most

[illegible]

The rest of the air which has served for combustion, and which chiefly consists of azotic gas, though still mixed with a considerable portion of oxygen gas which has escaped unchanged from the combustion, is carried through a third tube 28, 29, of deliquescent salts, to deprive it of any moisture it may have acquired in the bottles of alkaline solution and lime-water, and from thence by the tube 29, 30, into a gazometer, where its quantity is ascertained Small essays are then taken from it, which are exposed to a solution of sulphuret of potash, to ascertain the proportions of oxygen and azotic gas it contains

In the combustion of oils the wick becomes charred at last and obstructs the rise of the oil, besides, if we raise the wick above a certain height, more oil rises through its capillary tubes than the stream of air is capable of consuming, and smoke is produced Hence it is necessary to be able to lengthen or shorten the wick without opening the apparatus, this is accomplished by means of the rod 31, 32, 33, 34, which passes through a leather box and is connected with the support of the wick, and that the motion of this rod, and consequently of the wick, may be regulated with the utmost smoothness and facility, it is moved at pleasure by a pinion which plays in a toothed rack The rod, with

[illegible]

I shall not enter into a more detailed description of the construction of this apparatus, which is still capable of being altered and modified in many respects, but shall only add that when it

[illegible]

erable consequence in extensive experiments,

[illegible]

quently that they are composed of hydrogen and charcoal, but I have no certain knowledge respecting the proportions of these ingredients.

SECTION V *Of the Combustion of Alcohol*

The combustion of alcohol may be very readily performed in the apparatus already described for the combustion of charcoal and phosphorus A lamp filled with alcohol is placed under the

[illegible]

before directed This process is, however, liable to considerable inconvenience it is dangerous to make use of oxygen gas at the beginning of the experiment for fear of deflagration, which is even liable to happen when common air is employed An instance of this had very near proved fatal to myself, in presence of some members of the Academy Instead of preparing the experiment, as usual, at the time it was to be performed, I had disposed everything in order the evening before, the atmospheric air of the jar had thereby sufficient time to dissolve a good deal of the alcohol, and this evaporation had even been considerably promoted by the height of the column of mercury, which I had raised to EF (Plate IV, *Fig 3*) The moment I attempted to set the little morsel of phosphorus on fire by means of the red hot iron, a violent explosion took place, which threw the jar with great violence against the floor of the laboratory and dashed it in a thousand pieces

Hence we can only operate upon very small quantities, such as ten or twelve grains of alcohol, in this manner, and the errors which may be committed in experiments upon such small quantities prevents our placing any confidence in their results I endeavoured to prolong the combustion, in the experiments contained in the *Recueil de l'Académie* for 1784, p 593, by lighting the alcohol first in common air and furnishing oxygen gas afterwards to the jar, in proportion as it consumed, but the carbonic acid gas produced by the process became a great hinderance to the combustion, the more so that alcohol is but difficultly combustible, especially in worse than common air, so that even in this way very small quantities only could be burnt

[illegible]

cubic inches in dimension, and, were an explosion to take place in such a vessel, its consequences would be very terrible and very difficult to guard against I have not, however, despaired of making the attempt

From all these difficulties, I have been hitherto obliged to confine myself to experiments upon very small quantities of alcohol, or at least to combustions made in open vessels, such as that represented in Plate IX, *Fig 5*, which will be described in Section VII of this chapter If I am ever able to remove these difficulties, I shall resume this investigation

SECTION VI *Of the Combustion of Ether*

Tho' the combustion of ether in close vessels does not present the same difficulties as that of alcohol, yet it involves some of a different kind, not more easily overcome, and which still prevent the progress of my experiments I endeavoured to profit by the property which ether possesses of dissolving in atmospheric air and rendering it inflammable without explosion For this purpose, I constructed the reservoir of

[illegible]

passes through seven tubes *ef*, *gh*, *ik*, &c , which descend to the bottom of the ether, and it is forced by the pressure of the gazometer to boil up through the ether in the reservoir We may replace the ether in this first reservoir, in proportion as it is dissolved and carried off by the

[illegible]

ing ether to overcome the resistance occasioned by the pressure of the air from the gazometer

The air, thus loaded with vapours of ether, is conducted by the tube 5, 6, 7, 8, 9, to the jar A, into which it is allowed to escape through a capillary opening, at the extremity of which it is set on fire The air, when it has served the purpose of combustion, passes through the bottle 16 (Plate XI), the worm 17, 18, and the deliquescent tube 19, 20, after which it passes through the alkaline bottles in these its carbonic acid gas is absorbed, the water formed

[illegible]

(Plate XII, *Fig 8*) was in proper proportion for

[illegible]

these principles will burn in common air, which furnishes the quantity of oxygen necessary for combustion, but will not burn in close vessels in which the air is not renewed From this circumstance, my ether lamp went out soon after being lighted and shut up in the jar A (Plate xii, *Fig 8*) To remedy this defect, I endeavoured to bring atmospheric air to the lamp by the lateral tube 10, 11, 12, 13, 14, 15, which I distributed circularly round the flame, but the

I do not, however, despair of being able to accomplish it by means of some changes I am about to have made upon this apparatus

Section VII *Of the Combustion of Hydrogen Gas and the Formation of Water*

In the formation of water, two substances, hydrogen and oxygen, which are both in the aeriform state before combustion, are transformed into liquid or water by the operation This experiment would be very easy and would

ists have only employed oxygen gas mixed with azotic gas, from which circumstance, they have only been able to keep up the combustion of hydrogen gas for a very limited time in close vessels, because, as the residuum of azotic gas is continually increasing, the air becomes at last so much contaminated that the flame weakens and goes out This inconvenience is so much the greater in proportion as the oxygen gas employed is less pure From this circumstance, we

any admixture of azotic gas, and this may be procured from oxygenated muriate of potash. The oxygen gas extracted from this salt does not appear to contain azote, unless accidentally, so that, by proper precautions, it may be obtained perfectly pure In the mean time, the apparatus employed by M Meusnier and me for the combustion of hydrogen gas, which is described in the experiment for recomposition of water, Part I, Chapter VIII, and need not be here repeated, will answer the purpose, when pure gases are procured, this apparatus will require no alterations, except that the capacity of the vessels may then be diminished See Plate iv, *Fig 5*

The combustion, when once begun, continues for a considerable time but weakens gradually, in proportion as the quantity of azotic gas remaining from the combustion increases, till at last the azotic gas is in such over proportion that the combustion can no longer be supported, and the flame goes out This spontaneous extinction must be prevented, because, as the

superior pressure into the reservoir of oxygen

periments with the same scrupulous exactness as with the preceding instruments, gives very striking results that are extremely proper to be

for burning alcohol, &c

Things being thus disposed, and the lamp

should not be able to ascertain its quantity, and besides it might fall in drops upon the wick and extinguish the flame The intention of this construction is to keep the chimney always hot and the worm always cool, that the water may be preserved in the state of vapour whilst rising and may be condensed immediately upon getting into the descending part of the apparatus By this instrument, which was contrived by M Meusnier, and which is described by me in the *Recueil de l'Académie* for 1784, p 593, we may, with attention to keep the worm always cold, collect nearly seventeen ounces of water from the combustion of sixteen ounces of alcohol

SECTION VIII *Of the Oxidation of Metals*

The term *oxidation* or *calcination* is chiefly used to signify the process by which metals exposed to a certain degree of heat are converted into oxides by absorbing oxygen from the air This combination takes place in consequence of oxygen possessing a greater affinity to metals, at a certain temperature, than to caloric, which becomes disengaged in its free state, but, as this disengagement, when made in common air, is slow and progressive, it is scarcely evident to the senses It is quite otherwise however, when oxidation takes place in oxygen gas, for, being produced with much greater rapidity, it is generally accompanied with heat and light, so as evidently to show that metallic substances are real combustible bodies

All the metals have not the same degree of affinity to oxygen. Gold, silver, and platinum, for instance, are incapable of taking it away from its combination with caloric, even in the greatest known heat whereas the other metals absorb it in a larger or smaller quantity, until the affinities of the metal to oxygen, and of the latter to caloric, are in exact equilibrium Indeed, this state of equilibrium of affinities may be assumed as a general law of nature in all combinations

In all operations of this nature, the oxidation of metals is accelerated by giving free access to the air, it is sometimes much assisted by joining the action of a bellows, which directs a stream of air over the surface of the metal This process becomes greatly more rapid if a stream of oxygen gas be used, which is readily done by means of the gazometer formerly described The metal, in this case, throws out a brilliant flame, and the oxidation is very quickly accomplished; but this method can only be used in very confined experiments, on account of the expense of procuring oxygen gas In the essay of ores, and in all the common operations of the laboratory, the calcination or oxidation of metals is usually performed in a dish of baked clay (Plate IV, *Fig 6*), commonly called a *roasting test*, placed in a strong furnace The substances to be oxidated are frequently stirred, on purpose to present fresh surfaces to the air

Whenever this operation is performed upon a metal which is not volatile, and from which nothing flies off into the surrounding air during the process, the metal acquires additional weight, but the cause of this increased weight during oxidation could never have been discovered by means of experiments performed in free air and it is only since these operations have been performed in close vessels, and in determinate quantities of air, that any just conjectures have been formed concerning the cause of this phenomenon The first method for this purpose is due to Dr Priestley, who exposes the metal to be calcined in a porcelain cup N (Plate IV, *Fig 11*), placed upon the stand IK, under a jar A, in the basin BCDE full of water, the water is made to rise up to GH, by sucking out the air with a siphon, and the focus of a burning glass is made to fall upon the metal In a few minutes the oxidation takes place, a part of the oxygen contained in the air combines with the metal, and a proportional diminution of the volume of air is produced, what remains is nothing more than azotic gas, still however mixed with a small quantity of oxygen gas I have given an account of a series of experiments made with this apparatus in my *Physical and Chemical Essays*, first published in 1773 Mercury may be used instead of water in this experiment, whereby the results are rendered still more conclusive

Another process for this purpose was invented by M Boyle, of which I gave an account in the *Recueil de l'Académie* for 1774, p 351 The metal is introduced into a retort (Plate III, *Fig 20*), the beak of which is hermetically sealed, the metal is then oxidated by means of heat applied with great precaution The weight of the vessel and its contained substances is not at all changed by this process, until the extremity of the neck of the retort is broken but when that is done, the external air rushes in with a hissing noise This operation is attended with danger, unless a part of the air is driven out of the retort by means of heat before it is hermetically sealed, as otherwise the retort would be apt to burst by the dilation of the air when placed in the furnace The quantity of air driven out

may be received under a jar in the pneumato-chemical apparatus, by which its quantity and that of the air remaining in the retort is ascertained I have not multiplied my experiments upon oxidation of metals so much as I could have wished, neither have I obtained satisfactory results with any metal except tin It is much to be wished that some person would undertake a series of experiments upon oxidation of metals in the several gases the subject is important and would fully repay any trouble which this kind of experiment might occasion

As all the oxides of mercury are capable of revivifying without addition and restore the oxygen gas they had before absorbed, this seem-

[illegible]

a retort, containing a small quantity of mercury, with oxygen gas, and adapting a bladder half full of the same gas to its beak, See Plate IV, *Fig 12* Afterwards, by heating the mercury in the retort for a very long time, I suc-

[illegible]

in the determination of the quantities of oxygen gas before and after the operation must have thrown very great uncertainty upon the results of the experiment I was, besides, dissatisfied with this process, and not without cause, lest any air might have escaped through the pores of the bladder, more especially as it becomes shrivelled by the heat of the furnace unless covered over with cloths kept constantly wet

This experiment is performed with more certainty in the apparatus described in the *Recueil*

[illegible]

of experiment can only be performed upon a small scale, so that no very certain conclusions can be drawn from them [1]

[illegible]

refer the reader to what is said of it in that place Iron may likewise be oxidated by combustion in vessels filled with oxygen gas, in the way already directed for phosphorus and char-

[illegible]

fine wire or very thin plates cut into narrow slips, these are twisted round with iron wire, which communicates the property of burning to the other metals

Mercury is even with difficulty oxidated in free air In chemical laboratories, this process is usually carried on in a matrass A (Plate IV, *Fig 10*), having a very flat body and a very

[illegible]

six similar matrasses during several months,

[illegible]

[1] See an account of this experiment Part I, Chapter III —AUTHOR.

The oxide of mercury revives without addition, by being heated to a slightly red heat. In this degree of temperature, oxygen has greater affinity to caloric than to mercury, and forms oxygen gas This is always mixed with a small portion of azotic gas, which indicates that the mercury absorbs a small portion of this latter gas during oxidation It almost always contains a little carbonic acid gas, which must undoubtedly be attributed to the foulnesses of the oxide, these are charred by the heat, and convert a part of the oxygen gas into carbonic acid

If chemists were reduced to the necessity of procuring all the oxygen gas employed in their experiments from mercury oxidated by heat without addition, or, as it is called, *calcined or precipitated per se*, the excessive dearness of that preparation would render experiments, even upon a moderate scale, quite impracticable But mercury may likewise be oxidated by means of nitric acid, and in this way we procure a red oxide even more pure than that produced by calcination I have sometimes prepared this oxide by dissolving mercury in nitric acid, evaporating to dryness, and calcining the salt, either in a retort or in capsules formed of pieces of broken matrasses and retorts, in the manner formerly described but I have never succeeded in making it equally beautiful with what is sold by the druggists, and which is, I believe, brought from Holland In choosing this, we ought to prefer what is in solid lumps composed of soft adhering scales, as when in powder it is sometimes adulterated with red oxide of lead.

To obtain oxygen gas from the red oxide of mercury, I usually employ a porcelain retort having a long glass tube adapted to its beak, which is engaged under jars in the water pneumato-chemical apparatus, and I place a bottle in the water, at the end of the tube, for receiving the mercury, in proportion as it revives and distils over As the oxygen gas never appears till the retort becomes red, it seems to prove the principle established by M Berthollet that an obscure heat can never form oxygen gas and that light is one of its constituent elements We must reject the first portion of gas which comes over as being mixed with common air, from what was contained in the retort at the beginning of the experiment, but, even with this precaution, the oxygen gas procured is usually contaminated with a tenth part of azotic gas and with a very small portion of carbonic acid gas This latter is readily got rid of, by making the gas pass through a solution of caustic alkali, but we know of no method for separating the azotic gas, its proportions may however be ascertained, by leaving a known quantity of the oxygen gas contaminated with it for a fortnight, in contact with sulphuret of soda or potash, which absorbs the oxygen gas so as to convert the sulphur into sulphuric acid and leaves the azotic gas remaining pure

We may likewise procure oxygen gas from black oxide of manganese or nitrate of potash, by exposing them to a red heat in the apparatus already described for operating upon red oxide of mercury, only, as it requires such a heat as is at least capable of softening glass, we must employ retorts of stone or of porcelain But the purest and best oxygen gas is what is disengaged from oxygenated muriate of potash by simple heat This operation is performed in a glass retort, and the gas obtained is perfectly pure, provided that the first portions, which are mixed with the common air of the vessels, be rejected

CHAPTER IX

Of Deflagration

I HAVE already shown, Part I, Chapter IX, that oxygen does not always part with the whole of the caloric it contained in the state of gas when it enters into combination with other bodies It carries almost the whole of its caloric alongst with it in entering into the combinations which form nitric acid and oxygenated muriatic acid, so that in nitrates, and more especially in oxygenated muriates, the oxygen is, in a certain degree, in the state of oxygen gas, condensed, and reduced to the smallest volume it is capable of occupying

In these combinations, the caloric exerts a constant action upon the oxygen to bring it back to the state of gas, hence the oxygen adheres but very slightly, and the smallest additional force is capable of setting it free, and, when such force is applied, it often recovers the state of gas instantaneously This rapid passage from the solid to the aeriform state is called detonation, or fulmination, because it is usually accompanied with noise and explosion Deflagrations are commonly produced by means of combinations of charcoal either with nitre or oxygenated muriate of potash, sometimes, to assist the inflammation, sulphur is added, and, upon the just proportion of these ingredients, and the proper manipulation of the mixture, depends the art of making gun powder

As oxygen is changed, by deflagration with charcoal, into carbonic acid, instead of oxygen

gas, carbonic acid gas is disengaged, at least when the mixture has been made in just proportions In deflagration with nitre, azotic gas is likewise disengaged, because azote is one of the constituent elements of nitric acid

The sudden and instantaneous disengage-

accord with experiment I have tried some kinds which produced almost double the effect of ordinary gun powder, although they gave out a sixth part less of gas during deflagration It would appear that the quantity of caloric disengaged at the moment of detonation contributes considerably to the expansive effects produced, for, although caloric penetrates freely through the pores of every body in nature, it can only do so progressively, and in a given time, hence, when the quantity disengaged at once is too large to get through the pores of the surrounding bodies, it must necessarily act in the same way with ordinary elastic fluids and overturn everything that opposes its passage This must, at least in part, take place when gun powder is set on fire in a cannon, as, although the metal is permeable to caloric, the quantity disengaged at once is too large to find its way through the pores of the metal, it must therefore make an effort to escape on every side and, as the resistance all around, excepting

ture produced

It is very probable that water is decomposed during the deflagration of gun-powder, and that

expansive force in passing from the liquid to the aeriform state of existence

In the last place, as a portion of undecomposed water is reduced to vapour during the deflagration of gun powder, and as water, in *the state of gas, occupies seventeen or eighteen* hundred times more space than in its liquid state, this circumstance must likewise contribute largely to the explosive force of the powder

I have already made a considerable series of experiments upon the nature of the elastic fluids disengaged during the deflagration of nitre with charcoal and sulphur, and have made some, likewise, with the oxygenated muriate of potash This method of investigation leads to tolerably accurate conclusions with respect to the constituent elements of these salts Some of the principal results of these experiments, and of the consequences drawn from them respecting the analysis of nitric acid, are reported in the collection of *Memoires* presented to the Academy by foreign philosophers, Vol XI, p 625 Since then I have procured more convenient instruments, and I intend to repeat these experiments upon a larger scale, by which I shall procure more accurate precision in their results, the following, however, is the process I have hitherto employed I would very earnest-

possible issue for the air These are charged

introduced must be rammed down with a rammer nearly of the same caliber with the barrel, four or five lines at the muzzle must be left

the paste be too much wetted, it
fire, and if too dry, the deflagration
become too rapid and even dangerous

When the experiment is not intended to be rigorously exact, we set fire to the match, and, when it is just about to communicate with the charge, we plunge the pistol below a large bell-glass full of water in the pneumato-chemical apparatus The deflagration begins and continues in the water, and gas is disengaged with less or more rapidity, in proportion as the mixture is more or less dry So long as the deflagration continues, the muzzle of the pistol must be kept somewhat inclined downwards, to prevent the water from getting into its barrel In this manner I have sometimes collected the gas produced from the deflagration of an ounce and half, or two ounces, of nitre

In this manner of operating it is impossible to determine the quantity of carbonic acid gas disengaged, because a part of it is absorbed by the water while passing through it but, when the carbonic acid is absorbed, the azotic gas remains, and, if it be agitated for a few minutes in caustic alkaline solution, we obtain it pure and can easily determine its volume and weight We may even, in this way, acquire a tolerably exact knowledge of the quantity of carbonic acid by repeating the experiment a great many times, and varying the proportions of charcoal, till we find the exact quantity requisite to deflagrate the whole nitre employed Hence, by means of the weight of charcoal employed, we determine the weight of oxygen necessary for saturation and deduce the quantity of oxygen contained in a given weight of nitre

I have used another process, by which the results of this experiment are considerably more accurate, which consists in receiving the disengaged gases in bell glasses filled with mercury The mercurial apparatus I employ is large enough to contain jars of from twelve to fifteen pints in capacity, which are not very readily managed when full of mercury and even require to be filled by a particular method When the jar is placed in the cistern of mercury, a glass siphon is introduced, connected with a small air-pump by means of which the air is exhausted, and the mercury rises so as to fill the jar After this the gas of the deflagration is made to pass into the jar in the same manner as directed when water is employed

I must again repeat that this species of experiment requires to be performed with the greatest possible precautions I have sometimes seen, when the disengagement of gas proceeded with too great rapidity, jars filled with more than an hundred and fifty pounds of mercury driven off by the force of the explosion and broken to pieces, while the mercury was scattered about in great quantities

When the experiment has succeeded and the gas is collected under the jar, its quantity in general, and the nature and quantities of the several species of gases of which the mixture is composed, are accurately ascertained by the methods already pointed out in the second chapter of this part of my work I have been prevented from putting the last hand to the experiments I had begun upon deflagration, from their connection with the objects I am at present engaged in, and I am in hopes they will throw considerable light upon the operations belonging to the manufacture of gun-powder

CHAPTER X

Of the Instruments Necessary for Operating upon Bodies in Very High Temperatures

SECTION I *Of Fusion*

WE have already seen that, by aqueous solution in which the particles of bodies are separated from each other, neither the solvent nor the body held in solution are at all decomposed, so that, whenever the cause of separation ceases, the particles reunite, and the saline substance recovers precisely the same appearance and properties it possessed before solution Real solutions are produced by fire, or by introducing and accumulating a great quantity of caloric between the particles of bodies and this species of solution in caloric is usually called *fusion*

This operation is commonly performed in vessels called crucibles, which must necessarily be less fusible than the bodies they are intended to contain Hence, in all ages, chemists have been extremely solicitous to procure crucibles of very refractory materials, or such as are capable of resisting a very high degree of heat The best are made of very pure clay or of porcelain earth, whereas such as are made of clay mixed with calcareous or silicious earth are very fusible All the crucibles made in the neighbourhood of Paris are of this kind and consequently unfit for most chemical experiments The Hessian crucibles are tolerably good, but the best are made of Limoges earth, which seems absolutely infusible We have, in France, a great many clays very fit for making crucibles, such, for instance, is the kind used for making melting pots at the glass-manufactory of St Gobin

Crucibles are made of various forms, according to the operations they are intended to per-

form Several of the most common kinds are represented Plate VII, *Figs 7, 8, 9*, and *10*, the one represented at *Fig 9* is almost shut at its mouth

Though fusion may often take place without changing the nature of the fused body, this operation is frequently employed as a chemical means of decomposing and recompounding bodies In this way all the metals are extracted

to form glass, and by it likewise pastes, or coloured stones, enamels, &c are formed

The action of violent fire was much more frequently employed by the ancient chemists than it is in modern experiments Since greater precision has been employed in philosophical researches the *humid* has been preferred to the *dry* method of process, and fusion is seldom had recourse to until all the other means of analysis have failed

Section II *Of Furnaces*

These are instruments of most universal use

(Plate XIII, *Fig 1*), are made in its upper edge, as otherwise any pan which might be placed over the fire would stop the passage of the air, and prevent the fuel from burning This furnace can only produce a moderate degree of heat because the quantity of charcoal it is capable of consuming is limited by the quantity of air which is allowed to pass through the opening G of the ash hole Its power might be

of different sizes

The reverberatory furnace (Plate XIII, *Fig 2*) is perhaps more necessary This, like the

ditional tubes may be adapted, according to the nature of the different experiments The retort A is placed in the division called the laboratory and supported by two bars of iron which run across the furnace, and its beak comes out at a round hole in the side of the furnace one half of which is cut in the piece called the laboratory and the other in the dome In most of the ready made reverberatory furnaces which are sold by the potters at Paris, the openings both above and below are too small These do not allow a sufficient volume

which passes through the furnace, these fur-

the ash hole one of these is shut up when only a moderate fire is required, and both are kept open when the strongest power of the furnace is to be exerted The opening of the dome SS ought likewise to be considerably larger than is usually made

dome is to oblige the flame and heat to surround and strike back or reverberate upon every part of the retort, whence the furnace gets

place without anything passing over into the receiver, but, by means of the dome, the retort is equally heated in every part, and the vapours being forced out can only condense in the neck of the retort or in the recipient

To prevent the bottom of the retort from being either heated or cooled too suddenly, it is sometimes placed in a small sand bath of baked clay, standing upon the cross bars of the furnace Likewise, in many operations, the retorts are coated over with lutes, some of which are intended to preserve them from the too sudden influence of heat or of cold, while others are for sustaining the glass, or forming a kind of second retort, which supports the glass one during operations wherein the strength of the fire might soften it The former is made of brick-clay with a little cow's hair beat up along with it, into a paste or mortar, and spread over the glass or stone retorts The latter is made of pure clay and pounded stone-ware mixed together and used in the same manner This dries and hardens by the fire, so as to form a true supplementary retort capable of retaining the materials, if the glass retort below should crack or soften But, in experiments which are intended for collecting gases, this lute, being porous, is of no manner of use

In a great many experiments wherein very violent fire is not required, the reverberatory furnace may be used as a melting one, by leaving out the piece called the laboratory and placing the dome immediately upon the fireplace, as represented Plate XIII, Fig 3 The furnace represented in Fig 4 is very convenient for fusions, it is composed of the fire-place and ash-hole ABD, without a door, and having a hole E, which receives the muzzle of a pair of bellows strongly luted on, and the dome ABGH, which ought to be rather lower than is represented in the figure This furnace is not capable of producing a very strong heat but is sufficient for ordinary operations and may be readily moved to any part of the laboratory where it is wanted Though these particular furnaces are very convenient, every laboratory must be provided with a forge furnace, having a good pair of bellows, or, what is more necessary, a powerful melting furnace I shall describe the one I use, with the principles upon which it is constructed

The air circulates in a furnace in consequence of being heated in its passage through the burning coals, it dilates and, becoming lighter than the surrounding air, is forced to rise upwards by the pressure of the lateral columns of air, and is replaced by fresh air from all sides, especially from below This circulation of air even takes place when coals are burnt in a common chaffing dish, but we can readily conceive, that, in a furnace open on all sides, the mass of air which passes, all other circumstances being equal, cannot be so great as when it is obliged to pass through a furnace in the shape of a hollow tower, like most of the chemical furnaces, and consequently that the combustion must be more rapid in a furnace of this latter construction Suppose, for instance, the furnace ABCDEF open above and filled with burning coals, the force with which the air passes through the coals will be in proportion to the difference between the specific gravity of two columns equal to AC, the one of cold air without, and the other of heated air within the furnace There must be some heated air above the opening AB, and the superior levity of this ought likewise to be taken into consideration, but as this portion is continually cooled and carried off by the external air, it cannot produce any great effect

But, if we add to this furnace a large hollow tube GHAB of the same diameter, which preserves the air which has been heated by the burning coals from being cooled and dispersed by the surrounding air, the difference of specific gravity which causes the circulation will then be between two columns equal to GC Hence, if GC be three times the length of AC, the circulation will have treble force This is upon the supposition that the air in GHCD is as much heated as what is contained in ABCD, which is not strictly the case, because the heat must decrease between AB and GH, but, as the air in GHAB is much warmer than the external air, it follows that the addition of the tube must increase the rapidity of the stream of air, that a larger quantity must pass through the coals, and consequently that a greater degree of combustion must take place

We must not, however, conclude from these principles, that the length of this tube ought to be indefinitely prolonged, for, since the heat of the air gradually diminishes in passing from AB to GH, even from the contact of the sides of the tube, if the tube were prolonged to a certain degree, we would at last come to a point where the specific gravity of the included air would be equal to the air without, and, in this case, as the cool air would no longer tend to rise upwards, it would become a gravitating mass, resisting the ascension of the air below Besides, as this air, which has served for combus-

tion, is necessarily mixed with carbonic acid gas, which is considerably heavier than common air, if the tube were made long enough, the air might at last approach so near to the temperature of the external air as even to gravitate downwards hence we must conclude that the length of the tube added to a furnace must have some limit beyond which it weakens instead of strengthening the force of the fire

From these reflections it follows that the first foot of tube added to a furnace produces more effect than the sixth, and the sixth more than the tenth but we have no data to ascertain at what height we ought to stop This limit of useful addition is so much the farther in proportion as the materials of the tube are weaker conductors of heat, because the air will thereby be so much less cooled, hence baked earth is much to be preferred to plate iron It would be even of consequence to make the tube double,

air consequently increased, and by this means, the tube may be made *so much the longer*

As the fire-place is the hottest part of a furnace, and the part where the air is most dilated

age of the air which supports or rather produces the combustion, hence we only allow the interstices between the coals for the passage of the air

From these principles my melting furnace is constructed, which I believe is at least equal in power to any hitherto made, though I by no

made is still less understood, hence data are wanting by which to proceed upon principle and we can only accomplish the end in view by repeated trials

This furnace which according to the above stated rules, is in form of an eliptical *spheroid*, is represented Plate XIII *Fig 6*, ABCD it is cut off at the two ends by two planes, which

for the passage of the air That no obstacle may oppose the free access of external air, it is perfectly open below, after the model of M Macquer s melting furnace and stands upon an iron

ceptible of being considerably increased in power by the means already mentioned the principal of which is to render the tube as bad a conductor of heat as possible, by making it double, and filling the interval with rammed charcoal

When it is required to know if lead contains

sage through burning coals The furnace intended for answering this double purpose is called the cupelling or essay furnace It is usually made of a square form, as represented

laboratory of the furnace upon cross bars of iron, is adjusted to the opening GG, and luted with clay softened in water The cupels are

air is admitted through the door of the muffle GG for oxidating the contained metal

Very little reflection is sufficient to discover the erroneous principles upon which this furnace is constructed When the opening GG is shut, the oxidation is produced slowly and with difficulty, for want of air to carry it on, and, when this hole is open, the stream of cold air which is then admitted fixes the metal and obstructs the process These inconveniences may be easily remedied, by constructing the muffle and furnace in such a manner that fresh extern[illegible] surface of [illegible] made to pa[illegible] pe of clay kept continually red hot by the fire of the furnace By this means the inside of the muffle will never be cooled, and processes will be finished in a few minutes which at present require a considerable space of time

M Sage remedies these inconveniences in a different manner he places the cupel containing lead, alloyed with gold or silver, amongst the charcoal of an ordinary furnace and covered by a small porcelain muffle, when the whole is sufficiently heated, he directs the blast of a common pair of hand bellows upon the surface of the metal and completes the cupellation in this way with great ease and exactness

SECTION III *Of Increasing the Action of Fire by Using Oxygen Gas Instead of Atmospheric Air*

By means of large burning glasses, such as those of Tchirnausen and M de Trudaine, a degree of heat is obtained somewhat greater than has hitherto been produced in chemical furnaces, or even in the ovens of furnaces used for baking hard porcelain But these instruments are extremely expensive, and do not even produce heat sufficient to melt crude platinum, so that their advantages are by no means sufficient to compensate for the difficulty of procuring, and even of using them Concave mirrors produce somewhat more effect than burning glasses of the same diameter, as is proved by the experiments of MM Macquer and Beaumé with the speculum of the Abbé Bouriot, but, as the direction of the reflected rays is necessarily from below upwards, the substance to be operated upon must be placed in the air without any support, which renders most chemical experiments impossible to be performed with this instrument

For these reasons, I first endeavoured to employ oxygen gas for combustion, by filling large bladders with it, and making it pass through a tube capable of being shut by a stop cock, and in this way I succeeded in causing it to support the combustion of lighted charcoal. The intensity of the heat produced, even in my first attempt, was so great as readily to melt a small quantity of crude platinum To the success of this attempt is owing the idea of the gazometer, described p 91 *et seq*, which I substituted instead of the bladders, and, as we can give the oxygen gas any necessary degree of pressure, we can with this instrument keep up a continued stream and give it even a very considerable force

The only apparatus necessary for experiments of this kind consists of a small table ABCD (Plate XII, *Fig 15*), with a hole F, through which passes a tube of copper or silver, ending in a very small opening at G, and capable of being opened or shut by the stop-cock H This tube is continued below the table at *lmno* and is connected with the interior cavity of the gazometer When we mean to operate, a hole of a few lines deep must be made with a chisel in a piece of charcoal, into which the substance to be treated is laid, the charcoal is set on fire by means of a candle and blow-pipe, after which it is exposed to a rapid stream of oxygen gas from the extremity G of the tube FG

This manner of operating can only be used with such bodies as can be placed, without inconvenience, in contact with charcoal, such as metals, simple earths, &c But, for bodies whose elements have affinity to charcoal, and which are consequently decomposed by that substance, such as sulphates, phosphates, and most of the neutral salts, metallic glasses enamels, &c , we must use a lamp and make the stream of oxygen gas pass through its flame For this purpose, we use the elbowed blow pipe ST, instead of the bent one FG, employed with charcoal The heat produced in this second manner is by no means so intense as in the former way and is very difficultly made to melt platinum In this manner of operating with the lamp, the substances are placed in cupels of calcined bones, or little cups of porcelain, or even in metallic dishes If these last are sufficiently large, they do not melt, because, metals being good conductors of heat, *the caloric spreads rapidly* through the whole mass, so that none of its parts are very much heated

In the *Recueil de l'Académie* for 1782, p 476, and for 1783, p 573, the series of experiments I have made with this apparatus may be seen

at large The following are some of the principal results

1 Rock crystal, or pure silicious earth, is infusible, but becomes capable of being softened or fused when mixed with other substances

2 Lime, magnesia, and barytes, are infusible, either when alone, or when combined together, but, especially lime, they assist the fusion of every other body

3 Argill, or pure base of alum, is completely fusible *per se* into a very hard opaque vitreous substance, which scratches glass like the precious stones

4 All the compound earths and stones are readily fused into a brownish glass

5 All the saline substances, even fixed alkali, are volatilized in a few seconds

6 Gold silver, and probably platinum, are slowly volatilized without any particular phenomenon

7 All other metallic substances, except mercury, become oxidated, though placed upon charcoal, and burn with different coloured flames and at last dissipate altogether

8 *The metallic oxides likewise all burn with* flames This seems to form a distinctive character for these substances, and even leads me to believe, as was suspected by Bergman, that barytes is a metallic oxide, though we have not hitherto been able to obtain the metal in its pure or reguline state

and the Brazilian ruby, lose their colour very quickly and lose about a fifth of their weight, leaving a white earth, resembling white quartz or unglazed china The emerald, chrysolite, and garnet, are almost instantly melted into an opaque and coloured glass

10 The diamond presents a property peculiar to itself, it burns in the same manner with combustible bodies and is entirely dissipated

There is yet another manner of employing oxygen gas for considerably increasing the force of fire by using it to blow a furnace M Achard first conceived this idea but the process he employed by which he thought to dephlogisticate as it is called, atmospheric air, or to deprive it of azotic gas, is absolutely unsatisfactory I propose to construct a very simple furnace for this purpose, of very refractory earth, similar to the one represented Plate XIII, *Fig*

the oxygen gas from several gazometers, so

explosion

PLATE I

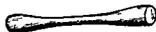



Fig 1

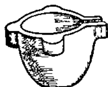



Fig 2

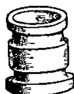



Fig 3




Fig 4




Fig 5

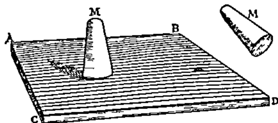


Fig 7



Fig 11




Fig 6



Fig 8



Fig 9



Fig 10



Fig 12

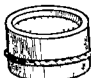


Fig 13

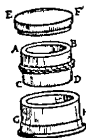


Fig 15

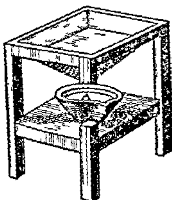


Fig 14



Fig 16

PLATE II


Fig 1

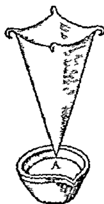


Fig 2


Fig 5


Fig 6


Fig 8


Fig 7

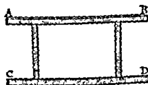


Fig 3

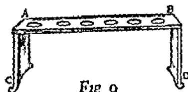


Fig 9



Fig 10

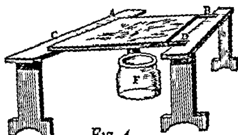


Fig 4

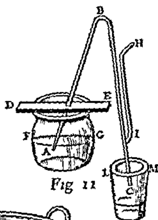


Fig 11


Fig 14


Fig 13



Fig 12


Fig 15


Fig 16


Fig 17

PLATE III

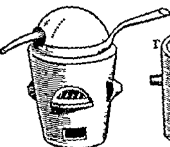


Fig 1

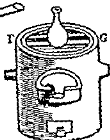


Fig 2

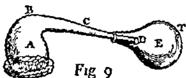


Fig 9



Fig 10



Fig 12



Fig 3



Fig 4



Fig 11



Fig 13

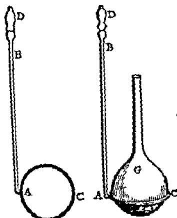


Fig 5 Fig 6

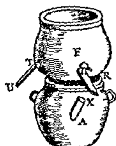


Fig 15



Fig 16

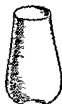


Fig 14



Fig 7



Fig 17

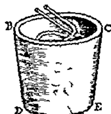


Fig 18

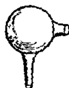


Fig 19

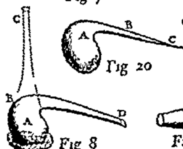


Fig 20

Fig 8



Fig 24



Fig. 21

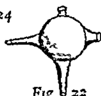


Fig 22



Fig 23

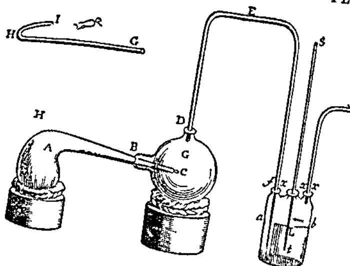


Fig 1

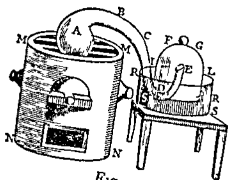


Fig 2

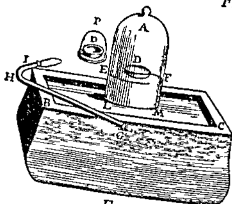


Fig 3

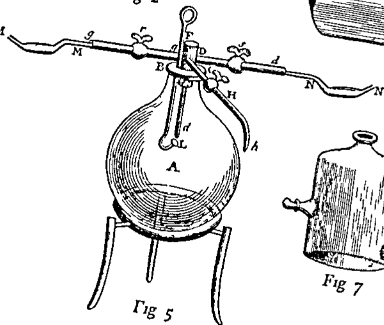


Fig 5

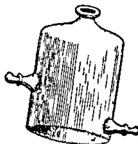
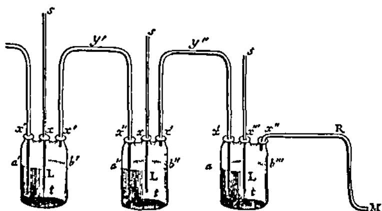

Fig 7


Fig 6


Fig 8



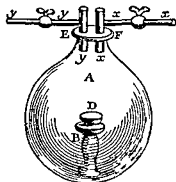


Fig 4

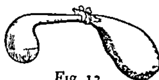


Fig 12



Fig 13

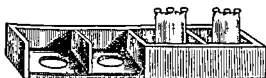


Fig 9

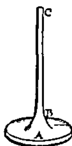


Fig 10



Fig 14

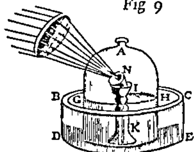


Fig 11



Fig 16

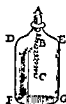
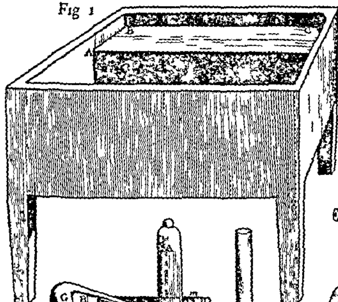


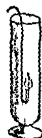
Fig 17



Fig 15

PLATE V




Fig 8

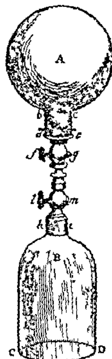


Fig 10


Fig 11

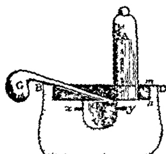


Fig 5


Fig 6

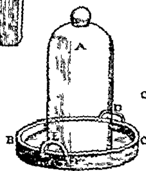
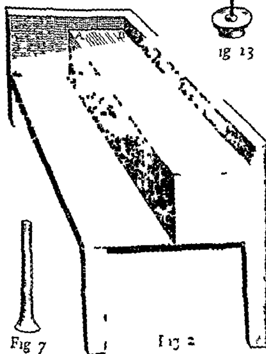


Fig 9


Fig 13


Fig 12


Fig 2

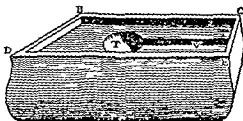


Fig 3

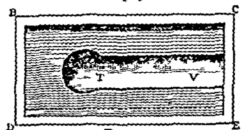


Fig 4


Fig 7

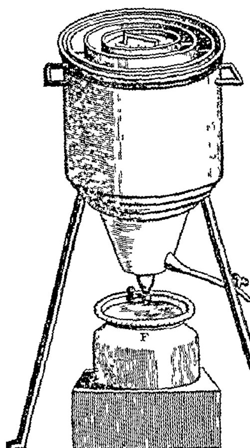


Fig 1



Fig 2



Fig 5



Fig 6



Fig 10

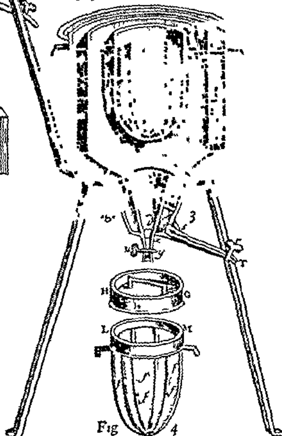


Fig 4



Fig 7

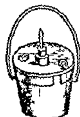


Fig 8



Fig 9

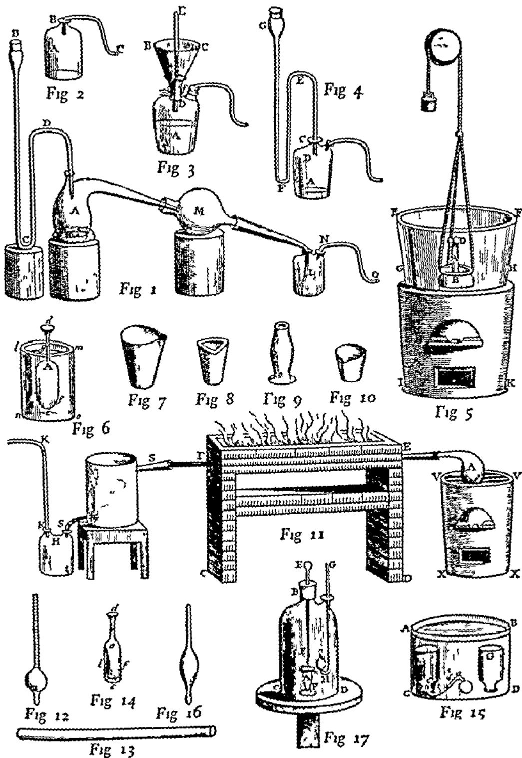


Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Fig 11
Fig 12
Fig 13
Fig 14
Fig 15
Fig 16
Fig 17

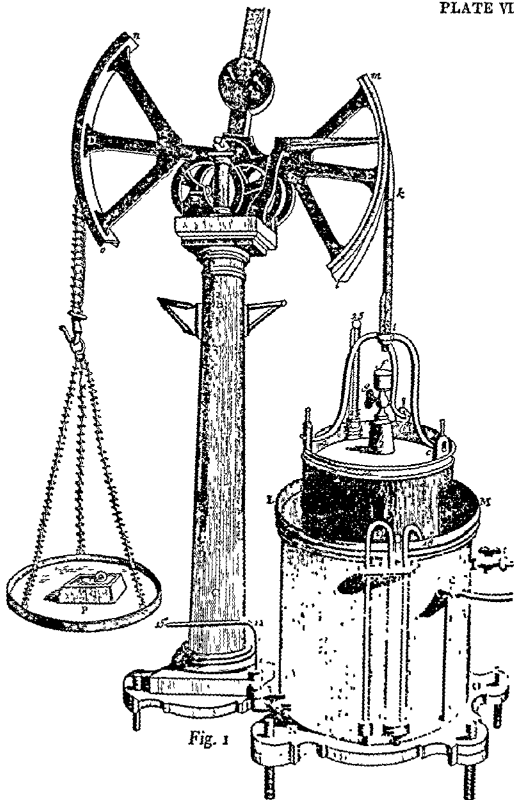


Fig. 1



Fig 2



Fig 4

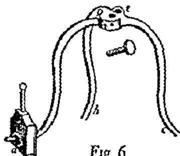


Fig 6

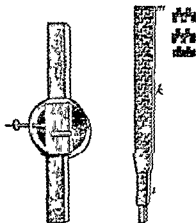


Fig 3

Fig. 5

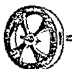


Fig 7

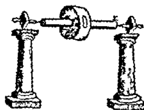


Fig 8

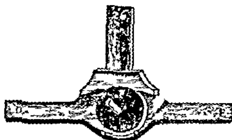


Fig 9

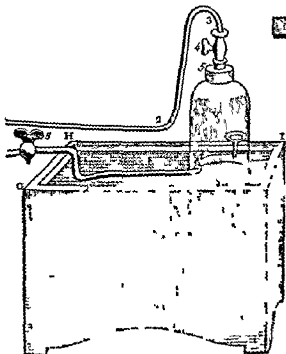




Fig 10

PLATE IX

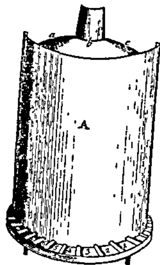


Fig 2

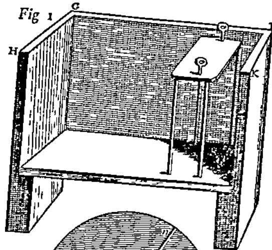


Fig 1

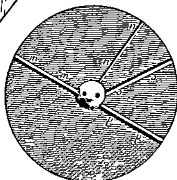


Fig 3







Fig 6

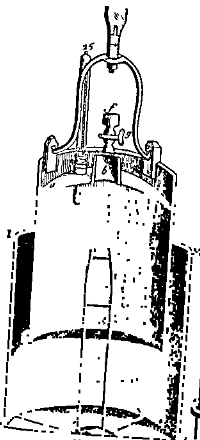


Fig 4

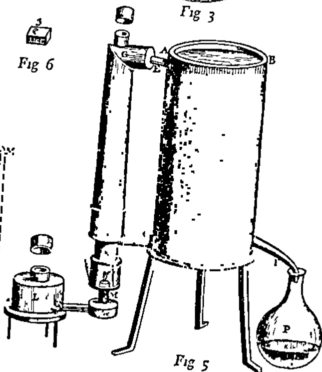
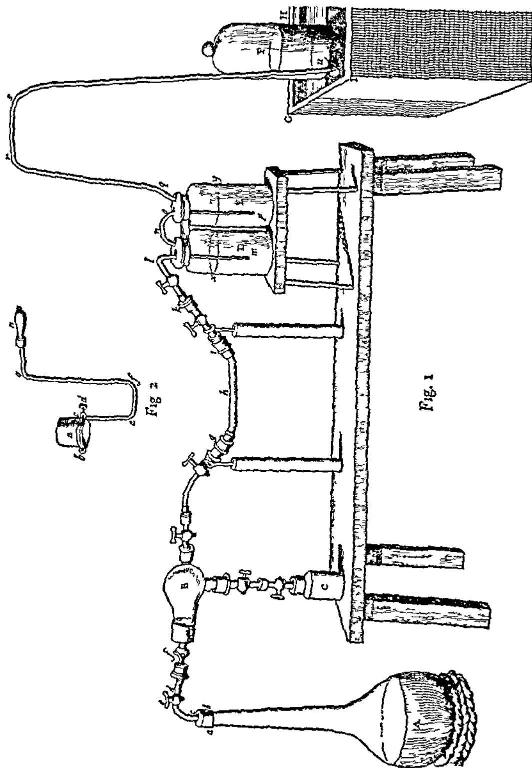
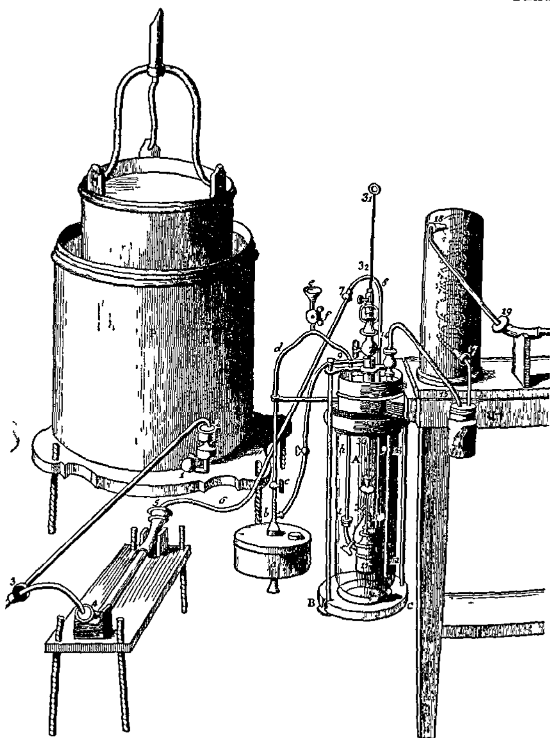


Fig 5

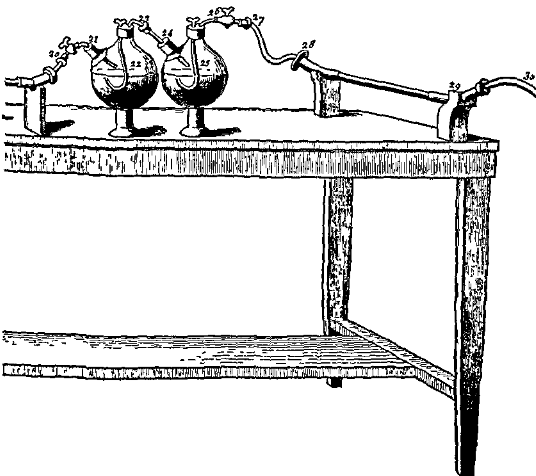
PLATE X



PLATE



XI



PLATE

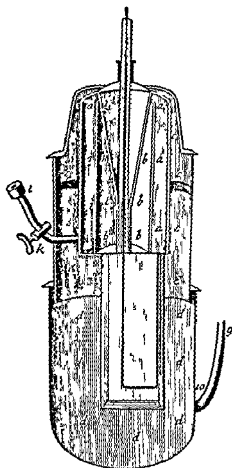


Fig 1

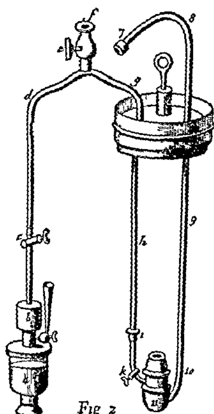


Fig 2



Fig 3



Fig 12

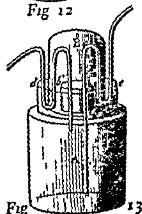


Fig 13

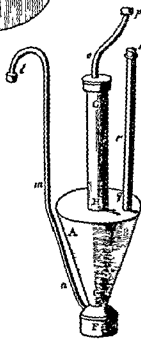


Fig 9





Fig 10

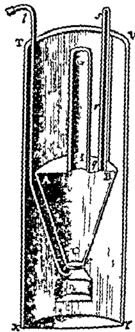


Fig 11

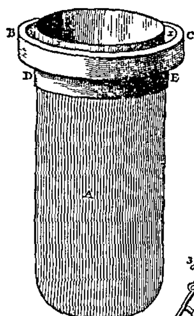


Fig 4





Fig 5



Fig 6

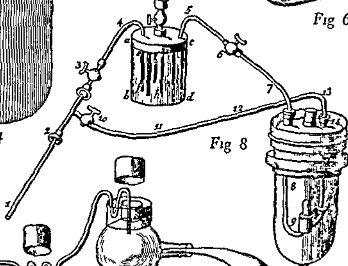


Fig 8



Fig 16



Fig 7

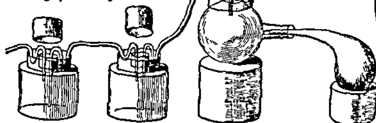


Fig 14

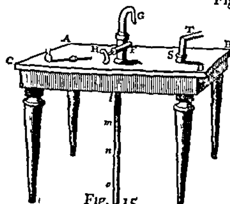


Fig. 15



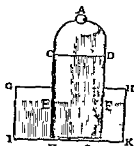


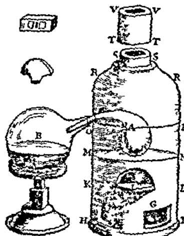
Fig 18

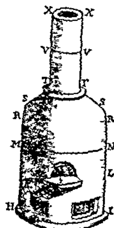


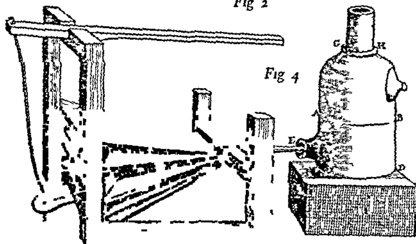
PLATE XIII

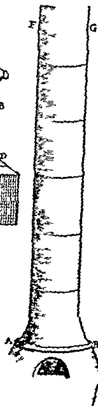

Fig 1


Fig 7


Fig 2


Fig 3


Fig 4



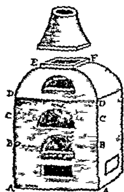
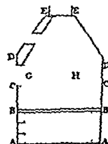
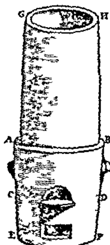

Fig 8


Fig 9




Fig 10


Fig 5

THEORY OF HEAT

BIOGRAPHICAL NOTE

Joseph Fourier, 1768-1830

Fourier was born at Auxerre March 21, 1768, the son of a poor tailor. An orphan at eight, he was recommended by a friend to the Bishop of Auxerre, who obtained admission for him in the local military school conducted by the Benedictines of Saint-Maur. He quickly distinguished himself as a student and showed distinct literary ability; at twelve he was writing sermons which were often used with great effect in Paris. At the age of thirteen mathematics began to attract him strongly. The prescribed hours of study did not suffice, he arose at night, concealed himself behind a screen, and by the light of candle-ends carefully collected during the day, pursued his mathematical studies. When he was twenty-one he delivered his first memoir before the Academy of Sciences on the resolution of numerical equations of all degrees.

Educated by monks in a military school, Fourier seems to have considered that only the army or the church could provide a career. With a strong recommendation from Legendre he applied for admission to the artillery. He was refused with the statement, "Fourier, not being of noble birth, cannot enter the artillery, not even if he is a second Newton." He then entered the Benedictine Order, where he remained as a novice from 1787 to 1789. Upon the outbreak of the Revolution he left the convent, although this did not result in any break with the Benedictines, since they immediately appointed him to the principal chair of mathematics at their school in Auxerre. When his colleagues became ill, he took their place, and besides teaching mathematics he also lectured on rhetoric, history, and philosophy.

At Auxerre, Fourier embraced the cause of the Revolution, joined the peoples' party, and served as publicist, recruiting agent, and member of the Citizens' Committee of Surveillance, in this last function he exercised such moderation that he was himself in danger from the Terror. When, in 1794, the Normal School was instituted at Paris to train a specially selected group of new teachers, Fourier was among the fifteen hundred that were chosen and, although he began as a student, he was soon made a "master of conference." The school failed after a short time, but Fourier had so impressed the authorities that when the Polytechnic School was founded, he was appointed to its faculty, first as "superintendent of lectures on fortification" and then as "lecturer on analysis."

Napoleon sometimes attended the sessions at the Polytechnic School, and when he organized the expedition to Egypt in 1798, Fourier was asked to be a part of it, although he was not informed of the role he was expected to play. Fourier was in Egypt for three years, engaged in the most varied activities: organizing factories for the army, constructing machines, leading scientific expeditions, and executing numerous administrative tasks. He acted as the representative of the general in-chief, receiving complaints from the Egyptian populace, and for one period was virtually governor of half of Egypt. On the death of General Kléber he was called upon to present a eulogy before the French Army. As secretary of the *Institute of Cairo* he instigated the collection of materials for the famous *Description of Egypt*. In collaboration with Napoleon he wrote the historical introduction to this work, which established his literary reputation and eventually won him membership in the French Academy.

On his return to France in 1802 Fourier was appointed prefect of the Département of Isère and for the next thirteen years lived at Grenoble. He composed the disputes between the different parties and brought order out of the confusion left by the Revolution in his province. As part of a general policy of public improvements he initiated an extensive road building project and undertook the reclamation of marsh-lands which had been the source of infection for thirty-seven communes. In recognition of his services he was created Baron of the Empire in 1808.

His many administrative duties as prefect of Isère did not interrupt his work as a mathematician and man of letters. He conducted inves-

tigations into the motions of heat in solid bodies with the aim of reducing them to mathematical formulation, and in 1807 submitted his first paper on the subject to the Academy of Sciences To induce the author to extend and improve his researches the Academy assigned as the problem for its prize competition of 1812, "The mathematical theory of the laws of the propagation of heat and the comparison of the results of this theory with exact experiment" The judges were Laplace, Lagrange, and Legendre, and they awarded the prize to Fourier for his memoir in two parts, *Théorie des mouvements de la chaleur dans les corps solides* The first part was republished in 1822 as the *Théorie Analytique de la Chaleur*.

Fourier continued to hold his position as prefect through the Revolution of 1814, but Napoleon's return from Elba proved to be his political downfall As Napoleon was approaching Grenoble, Fourier went to Lyons to notify the Bourbons that the city would undoubtedly capitulate They refused to believe him and made him responsible for the safety of the city Upon his return to Grenoble, which had surrendered, he was taken prisoner and brought before the Emperor Napoleon confronted him "You also have declared war against me? . . It only grieves me to see among my enemies an *Egyptian*, a man who has eaten along with me the bread of the bivouac, an old friend How, moreover, could you have forgotten, Monsieur Fourier, that I have made you what you are?" Fourier's loyalty was re-established, although he did not share Napoleon's confidence of victory. The end of the Hundred Days and the Restoration found him deprived of political office, in disgrace, and almost penniless.

A friend and former pupil who was prefect of Paris made it possible for him to become Director of the Bureau of Statistics, which he remained until his death His political past, however, did not prevent renewed recognition of his scientific abilities In 1816 he was proposed for membership in the Academy of Sciences, and although Louis XVIII refused his consent at that time, he became a member the following year He was made permanent secretary of the Division of Mathematical Sciences in 1822, member of the French Academy in 1826, and a year later succeeded Laplace as President of the Council for Improving the Polytechnic School In 1828 he became a member of the government commission established for the encouragement of literature.

He died May 16, 1830, of aneurism of the heart, which had been aggravated by his habit of wrapping himself in all seasons like "an Egyptian mummy" and living in airless rooms at an excessively high temperature

CONTENTS

CHAPTER I. INTRODUCTION

CHAPTER II EQUATIONS OF THE MOVEMENT OF HEAT

heat I then perceived that all the phenomena which depend on this action resolve themselves into a *very small number of general and simple facts, whereby* every physical problem of this kind is brought back to an investigation of mathematical analysis From these general facts I have concluded that to *determine numerically the most varied movements of heat, it is sufficient to submit* each substance to three fundamental observations Different bodies in fact do not possess in the same degree the power to *contain* heat, *to receive or transmit it across their surfaces, nor to conduct* it through the interior of their masses. These are the three specific qualities which our theory clearly distinguishes and shews how to measure

It is easy to judge how much these researches concern the physical sciences and civil economy, and what may be their influence on the progress of the arts which require the employment and distribution of heat They have also a necessary connection with the system of the world, and their relations become known when we consider the grand phenomena which take place near the surface of the terrestrial globe

In fact, the radiation of the sun in which this planet is incessantly plunged, penetrates the air, the earth, and the waters, its elements are divided, change in direction every way, and, penetrating the mass of the globe, would raise its mean temperature more and more, if the heat acquired were not exactly balanced by that which escapes *in rays from all points of the surface and* expands through the sky

Different climates, unequally exposed to the action of solar heat, have, after *an immense time, acquired the temperatures proper to their situation* This effect is modified by several accessory causes, such as elevation, the form of the ground, the neighbourhood and extent of continents and seas, the state of the *surface, the direction of the winds*

The succession of day and night, the alternations of the seasons occasion in the solid earth periodic variations, which are repeated every day or every year *but these changes become less and less sensible as the point at which they* are measured recedes from the surface No diurnal variation can be detected at the depth of about three metres [ten feet], and the annual variations cease to be *appreciable at a depth much less than sixty metres The temperature at great* depths is then sensibly fixed at a given place but it is not the same at all points of the same meridian in general it rises as the equator is approached

The heat which the sun has communicated to the terrestrial globe, and which has produced the diversity of climates, is now subject to a movement which has become uniform It advances within the interior of the mass which *it penetrates throughout, and at the same time recedes from the plane of the* equator, and proceeds to lose itself across the polar regions

In the higher regions of the atmosphere the air is very rare and transparent, *and retains but a minute part of the heat of the solar rays this is the cause* of the excessive cold of elevated places The lower layers, denser and more heated by the land and water, expand and rise up they are cooled by the very fact *of expansion The great movements of the air, such as the trade winds* which blow between the tropics, are not determined by the attractive forces of the moon and sun The action of these celestial bodies produces scarcely percepti*ble oscillations in a fluid so rare and at so great a distance* It is the changes of temperature which periodically displace every part of the atmosphere

The waters of the ocean are differently exposed at their surface to the rays

of the sun, and the bottom of the basin which contains them is heated very unequally from the poles to th[illegible]

those general and regular currents which navigators have noticed

Radiant heat which escapes from the surface of all bodies, and traverses elastic media, or spaces void of air, has special laws, and occurs with widely varied phenomena The physical explanation of many of these facts is already known, the mathematical theory which I have formed gives an exact measure of them It consists, in a manner, in a new catoptrics which has its own theorems, and serves to determine by analysis all the effects of heat direct or reflected

The enumeration of the chief objects of the theory sufficiently shews the na- [illegible]

sioning an oscillation of the solar heat beneath the surface, what relation is there between the duration of its period, and the depth at which the temperatures become constant?

What time must have elapsed before the climates could acquire the different temperatures which they now maintain, and what are the different causes which can now vary their mean heat? Why do not the annual changes alone in the distance of the sun from the earth, produce at the surface of the earth very considerable changes in the temperatures?

From what characteristic can we ascertain that the earth has not entirely lost its original heat, and what are the exact laws of the loss?

If, as several observations indicate, this fundamental heat is not wholly dissipated, it must be immense at great depths, and nevertheless it has no sensible influence at the present time on the mean temperature of the climates The effects which are observed in them are due to the action of the solar rays But independently of these two sources of heat, the one fundamental and primitive proper to the terrestrial globe, the other due to the presence of the sun, is there not a more universal cause, which determines *the temperature of the heavens*, in that part of space which the solar system now occupies? Since the observed facts necessitate this cause, what are the consequences of an exact theory in this entirely new question; how shall we be able to determine that constant value of *the temperature of space*, and deduce from it the temperature which belongs to each planet?

To these questions must be added others which depend on the properties of radiant heat The physical cause of the reflection of cold, that is to say the reflection of a lesser degree of heat, is very distinctly known, but what is the mathematical expression of this effect?

On what general principles do the atmospheric temperatures depend, whether the thermometer which measures them receives the solar rays directly, on a surface metallic or unpolished, or whether this instrument remains exposed, during the night, under a sky free from clouds, to contact with the air,

to radiation from terrestrial bodies, and to that from the most distant and coldest parts of the atmosphere?

The intensity of the rays which escape from a point on the surface of any heated body varying with their inclination according to a law which experiments have indicated, is there not a necessary mathematical relation between this law and the general fact of the equilibrium of heat, and what is the physical cause of this inequality in intensity?

Lastly, when heat penetrates fluid masses, and determines in them internal movements by continual changes of the temperature and density of each molecule, can we still express, by differential equations, the laws of such a compound effect, and what is the resulting change in the general equations of hydrodynamics?

Such are the chief problems which I have solved, and which have never yet been submitted to calculation If we consider further the manifold relations of this mathematical theory to civil uses and the technical arts, we shall recognize completely the extent of its applications It is evident that it includes an entire series of distinct phenomena and that the study of it cannot be omitted without losing a notable part of the science of nature

The principles of the theory are derived as are those of rational mechanics, from a very small number of primary facts, the causes of which are not considered by geometers, but which they admit as the results of common observations confirmed by all experiment

The differential equations of the propagation of heat express the most general conditions, and reduce the physical questions to problems of pure analysis

established

o make this

rations analogous to those of the theorems which serve as the foundation of statics and dynamics These equations still exist, but receive a different form, when they express the distribution of luminous heat in transparent bodies, or the movements which the changes of temperature and density occasion in the interior of fluids The coefficients which they contain are subject to variations whose exact measure is not yet known but in all the natural problems which it most concerns us to consider, the limits of temperature differ so little that we may omit the variations of these coefficients

The equations of the movement of heat, like those which express the vibrations of sonorous bodies or the ultimate oscillations of liquids, belong to one of the most recently discovered branches of analysis, which it is very important

tion requires a special analysis founded on new theorems whose object we could not in this place make known The method which is derived from them

The same theorems which have made known to us the equations of the movement of heat, apply directly to certain problems of general analysis and dynamics whose solution has for a long time been desired

Profound study of nature is the most fertile source of mathematical discov-

eries Not only has this study in offering a determinate object to investigation,

natural effects

We see, for example, that the same expression whose abstract properties

lems of the theory of probability

The analytical equations unknown to the ancient geometers which Descartes was the first to introduce into the study of curves and surfaces are not restricted to the properties of figures, and to those properties which are the object of rational mechanics they extend to all general phenomena There cannot be a language more universal and more simple more free from errors and from obscurities, that is to say more worthy to express the invariable relations of natural things

Considered from this point of view, mathematical analysis is as extensive as nature itself it defines all perceptible relations, measures times spaces forces, temperatures, this difficult science is formed slowly, but it preserves every principle which it has once acquired, it grows and strengthens itself incessantly in the midst of the many variations and errors of the human mind

great number of centuries, if the actions of gravity and of heat are exerted in the interior of the earth at depths which will be always inaccessible, mathematical analysis can yet lay hold of the laws of these phenomena It makes

senses, it would produce in us an impression comparable to the sensation of musical sound

The forms of bodies are infinitely varied, the distribution of the heat which penetrates them seems to be arbitrary and confused, but all the inequalities are rapidly cancelled and disappear as time passes on The progress of the phenomenon becomes more regular and simpler, remains finally subject to a definite law which is the same in all cases, and which bears no sensible impress of the initial arrangement

All observation confirms these consequences The analysis from which they are derived separates and expresses clearly first, the general conditions, that is

to say those which spring from the natural properties of heat, second, the effect, accidental but continued, of the form or state of the surfaces, third, the effect, not permanent, of the primitive distribution

In this work we have demonstrated all the principles of the theory of heat, and solved all the fundamental problems They could have been explained more concisely by omitting the simpler problems, and presenting in the first instance the most general results, but we wished to shew the actual origin of the theory and its gradual progress When this knowledge has been acquired and the principles thoroughly fixed, it is preferable to employ at once the most extended analytical methods, as we have done in the later investigations This is also the course which we shall hereafter follow in the memoirs which will be added to this work, and which will form in some manner its complement, and by this means we shall have reconciled, so far as it can depend on ourselves, the necessary development of principles with the precision which becomes the applications of analysis

The subjects of these memoirs will be, the theory of radiant heat, the problem of the terrestrial temperatures, that of the temperature of dwellings, the comparison of theoretic results with those which we have observed in different experiments, lastly the demonstrations of the differential equations of the movement of heat in fluids

The work which we now publish has been written a long time since, different circumstances have delayed and often interrupted the printing of it In this interval science has been enriched by important observations the principles of our analysis which had not at first been grasped, have become better known the results which we had deduced from them have been discussed and confirmed We ourselves have applied these principles to new problems, and have changed the form of some of the proofs The delays of publication will have contributed to make the work clearer and more complete

The subject of our first analytical investigations on the transfer of heat was its distribution amongst separated masses, these have been preserved in Chapter IV, Section II The problems relative to continuous bodies, which form the theory rightly so called, were solved many years afterwards, this theory was

this memoir, and successively forwarded very extensive notes, concerning the

ond memoir, on the propagation of heat, was deposited in the archives of the Institute, on the 28th of September, 1811 It was formed out of the preceding memoir and the notes already sent in, the geometrical constructions and those details of analysis which had no necessary relation to the physical problem were omitted, and to it was added the general equation which expresses the state of the surface This second work was sent to press in the course of 1821,

thout

ianu-

first

will

be treated in the subsequent memoirs at greater length, and, if it be in our power, with greater clearness The results of our labours concerning the same problems are also indicated in several articles already published The extract inserted in the *Annales de Chimie et de Physique* shews the aggregate of our researches (Vol III, page 350, year 1816) We published in the *Annales* two separate notes, concerning radiant heat (Vol IV, page 128, year 1817, and Vol VI, page 259, year 1817)

Several other articles of the same collection present the most constant results of theory and observation, the utility and the extent of thermological knowledge could not be better appreciated than by the celebrated editors of the *Annales* [1]

[illegible] 1818 [illegible] our analysis of the terrestrial temperatures

M Alexandre de Humboldt, whose researches embrace all the great prob- [illegible] ions of the tempera- [illegible] very important point [illegible] Vol III, page 462), (Memoir on the inferior limit of perpetual snow, *Annales de Chimie et de Physique*, Vol V, page 102, year 1817)

As to the differential equations of the movement of heat in fluids mention has been made of them in the annual history of the Academy of Sciences The extract from our memoir shews clearly its object and principle (*Analyse des* [illegible] 1820) [illegible] we have considered This question connected with the theory of radiant heat has just been discussed by the illustrious author of the *Mécanique céleste*, to whom all the chief branches of mathematical analysis owe important discoveries (*Connaissance des Temps*, years 1824–5)

The new theories explained in our work are united for ever to the mathematical sciences, and rest like them on invariable foundations, all the elements which they at present possess they will preserve, and will continually acquire greater extent Instruments will be perfected and experiments multiplied The analysis which we have formed will be deduced from more general, that is to [illegible] common to many classes of phe- [illegible] phenomena the expression of the laws of nature, but the special application of these laws to very complex effects demands a long series of exact observations.

[1] Gay Lussac and Arago.

FIRST CHAPTER

Introduction

SECTION I *Statement of the Object of the Work*

1 The effects of heat are subject to constant laws which cannot be discovered without the aid of mathematical analysis The object of the theory which we are about to explain is to demonstrate these laws it reduces all physical researches on the propagation of heat to problems of the integral calculus whose elements are given by experiment No subject has more extensive relations with the progress of industry and the natural sciences for the action of heat is always present it penetrates all bodies and spaces it influences the processes of the arts and occurs in all the phenomena of the universe

When heat is unequally distributed among the different parts of a solid mass it tends to attain equilibrium and passes slowly from the parts which are more heated to those which are less and at the same time it is dissipated at the surface and lost in the medium or in the void The tendency to uniform distribution and the spontaneous emission which acts at the surface of bodies change continually the temperature at their different points The problem [illegible]

of these problems

2 If we expose to the continued and uniform action of a source of heat the same part of a metallic ring whose diameter is large the molecules nearest to the source will be first heated and after a certain time every point of the solid will have acquired very nearly the highest temperature which it can attain This limit or greatest temperature is not the same at different points it becomes less and less according as they become more distant from that point at which the source of heat is directly applied

When the temperatures have become permanent the source of heat supplies at each instant a quantity of heat which exactly compensates for that which is dissipated at all the points of the external surface of the ring [illegible]

equal to the temperatures of the surrounding medium

3 Whilst the temperatures are permanent and the source remains if at every point of the mean circumference of the ring an ordinate be raised perpendicular to the plane of the ring whose length is proportional to the fixed temperature at that point the curved line which passes through the ends of these ordinates will represent the permanent state of the temperatures and it is very easy to determine by analysis the nature of this line It is to be remarked

that the thickness of the ring is supposed to be sufficiently small for the temperature to be sensibly equal at all points of the same section perpendicular to the mean circumference When the source is removed, the line which bounds the ordinates proportional to the temperatures at the different points will

4 Let z be the constant temperature at a point m of the mean circumference x the distance of this point from the source that is to say the length of the arc of the mean circumference, included between the point m and the point o which corresponds to the position of the source z is the highest temperature which the point m can attain by virtue of the constant action of the source, and this permanent temperature z is a function $f(x)$ of the distance x The first part of the problem consists in determining the function $f(x)$ which represents the permanent state of the solid

Consider next the variable state which succeeds to the former state as soon as the source has been removed, denote by t the time which has passed since the suppression of the source, and by v the value of the temperature at the point m after the time t The quantity v will be a certain function $F(x, t)$ of the distance x and the time t, the object of the problem is to discover this function $F(x, t)$, of which we only know as yet that the initial value is $f(x)$, so

here or
emains

immersed for a very long time, it will acquire at all its points a temperature differing very little from that of the fluid Suppose the mass to be withdrawn in order to transfer it to a cooler medium, heat will begin to be dissipated at its surface, the temperatures at different points of the mass will not be sensibly the same, and if we suppose it divided into an infinity of layers by surfaces parallel to its external surface, each of those layers will transmit, at each instant, a certain quantity of heat to the layer which surrounds it If it be imagined that each molecule carries a separate thermometer, which indicates its temperature at every instant, the state of the solid will from time to time be represented by the variable system of all these thermometric heights It is required to express the successive states by analytical formulæ, so that we may

6 If the mass is spherical, and we denote by x the distance of a point of this mass from the centre of the sphere, by t the time which has elapsed since the commencement of the cooling, and by v the variable temperature of the point m, it is easy to see that all points situated at the same distance x from the centre of the sphere have the same temperature v This quantity v is a certain function $F(x, t)$ of the radius x and of the time t it must be such that it becomes

for by

emersic

expresses the value of v

7 In the next place it is to be remarked, that during the cooling a certain quantity of heat escapes, at each instant, through the external surface, and

passes into the medium The value of this quantity is not constant, it is greatest at the beginning of the cooling If however we consider the variable state of the internal spherical surface whose radius is x, we easily see that there must be at each instant a certain quantity of heat which traverses that surface, and passes through *that part of the mass which is more distant from the* centre This continuous flow of heat is variable like that through the external surface, and both are quantities comparable with each other, their ratios are numbers whose varying values are functions of the distance x, and of the time t which has elapsed It is required to determine these functions

8 If the mass, which has been heated by a long immersion in a medium, and

faces, we see that the temperature v of the point m after the time t, is a function of the four variables x, y, z, and t The quantities of heat which flow out at each instant through the whole external surface of the solid, are variable and comparable with each other, their ratios are analytical functions depending on the time t, the expression of which must be assigned

9 Let us examine also the case in which a rectangular prism of sufficiently great thickness and of infinite length, being submitted at its extremity to a constant temperature, whilst the air which surrounds it is maintained at a less temperature, has at last arrived at a fixed state which it is required to determine All the points of the extreme section at the base of the prism have, by hypothesis, a common and permanent temperature It is not the same with a section distant from the source of heat, each of the points of this rectangular surface parallel to the base has acquired a fixed temperature, but this is not the same at different points of the same section, and must be less at points nearer to the surface exposed to the air We see also that, at each instant, there flows across a given section a certain quantity of heat, which always remains the same, since the state of the solid has become constant The problem consists in determining the permanent temperature at any given point of the solid, and the whole quantity of heat which, in a definite time, flows across a section whose position is given

nates are x, y, z, is a function of three variables $F(x, y, z)$ it has by hypothesis a constant value, when we suppose x nothing, whatever be the values of y and z Suppose we take for the unit of heat that quantity which in the unit of time would emerge from an area equal to a unit of surface if the heated mass which that area bounds, and which is formed of the same substance as the prism, were continually maintained at the temperature of boiling water, and immersed in atmospheric air maintained at the temperature of melting ice

We see that the quantity of heat which, in the permanent state of the rectangular prism, flows, during a unit of time, across a certain section perpendicular to the axis, has a determinate ratio to the quantity of heat taken as unit This ratio is not the same for all sections it is a function $\phi(x)$ of the distance x, at which the section is situated It is required to find an analytica expression of the function $\phi(x)$

11 The foregoing examples suffice to give an exact idea of the different problems which we have discussed

The solution of these problems has made us understand that the effects of the propagation of heat depend in the case of every solid substance, on three elementary qualities, which are, its capacity for heat, its own conductivity, and the exterior conductivity

It has been observed that if two bodies of the same volume and of different nature have equal temperatures, and if the same quantity of heat be added to them, the increments of temperature are not the same, the ratio of these increments is the inverse ratio of their capacities for heat In this manner, the first of the three specific elements which regulate the action of heat is exactly defined, and physicists have for a long time known several methods of determining its value It is not the same with the two others, their effects have often been observed, but there is but one exact theory which can fairly distinguish, define, and measure them with precision

The proper or interior conductivity of a body expresses the facility with which heat is propagated in passing from one internal molecule to another The external or relative conductivity of a solid body depends on the facility with which heat penetrates the surface, and passes from this body into a given medium, or passes from the medium into the solid The last property is modified by the more or less polished state of the surface, it varies also according to the medium in which the body is immersed, but the interior conductivity can change only with the nature of the solid

These three elementary qualities are represented in our formulæ by constant numbers, and the theory itself indicates experiments suitable for measuring their values As soon as they are determined, all the problems relating to the propagation of heat depend only on numerical analysis The knowledge of these specific properties may be directly useful in several applications of the physical sciences, it is besides an element in the study and description of different substances It is a very imperfect knowledge of bodies which ignores the relations which they have with one of the chief agents of nature In general, there is no mathematical theory which has a closer relation than this with public economy, since it serves to give clearness and perfection to the practice of the numerous arts which are founded on the employment of heat

12 The problem of the terrestrial temperatures presents one of the most beautiful applications of the theory of heat, the general idea to be formed of it is this Different parts of the surface of the globe are unequally exposed to the influence of the solar rays, the intensity of their action depends on the latitude of the place, it changes also in the course of the day and in the course of the year, and is subject to other less perceptible inequalities It is evident that, between the variable state of the surface and that of the internal temperatures, a necessary relation exists, which may be derived from theory We know that, at a certain depth below the surface of the earth, the temperature at a given

molecule has also a fixed temperature determined by its position The mathematical problem consists in discovering the fixed temperature at any given point and the law which the solar heat follows whilst penetrating the interior of the earth

This diversity of temperature interests us still more if we consider the changes which succeed each other in the envelope itself on the surface of which we dwell Those alternations of heat and cold which are reproduced every day and in the course of every year have been up to the present time the object of repeated observations These we can now submit to calculation and from a common theory derive all the particular facts which experience has taught us

epoch of the changes and how the fixed value of the underground temperature is deduced from the variable temperatures observed at the surface

from them the values of the temperatures after a definite time The numerical

the temperatures must satisfy but the functions themselves will be given under a form which facilitates the numerical applications

14 In order that these solutions might be general and have an extent equal *to that of the problem it was requisite that they should accord* with the initial state of the temperatures which is arbitrary The examination of this condition shews that we may develop in convergent series or express by definite integrals

arbitrary functions by submitting them to the ordinary processes of analysis

15 It still remained to compare the facts with theory With this view varied and exact experiments were undertaken whose results were in conformity with those of analysis and gave them an authority which one would have been disposed to refuse to them in a new matter which seemed subject to so much uncertainty These experiments confirm the principle from which we started, and which is adopted by all physicists in spite of the diversity of their hypotheses on the nature of heat

16 Equilibrium of temperature is effected not only by way of contact, it is established also between bodies separated from each other, which are situated for a long time in the same region This effect is independent of contact with a medium, we have observed it in spaces wholly void of air To complete our theory it was necessary to examine the laws which radiant heat follows, on leaving the surface of a body It results from the observations of many physicists and from our own experiments, that the intensities of the different rays, which escape in all directions from any point in the surface of a heated body, depend on the angles which their directions make with the surface at the same point We have proved that the intensity of a ray diminishes as the ray makes

librium of temperature and of the laws of propagation of heat in solid bodies

Such are the chief problems which have been discussed in this work, they are all directed to one object only, that is to establish clearly the mathematical principles of the theory of heat, and to keep up in this way with the progress of the useful arts, and of the study of nature

17 From what precedes it is evident that a very extensive class of phenomena exists, not produced by mechanical forces, but resulting simply from the presence and accumulation of heat This part of natural philosophy cannot be connected with dynamical theories, it has principles peculiar to itself, and is founded on a method similar to that of other exact sciences The solar heat, for example, which penetrates the interior of the globe, distributes itself therein according to a regular law which does not depend on the laws of motion, and cannot be determined by the principles of mechanics The dilatations which the repulsive force of heat produces, observation of which serves to measure temperatures, are in truth dynamical effects, but it is not these dilatations which we calculate, when we investigate the laws of the propagation of heat

18 There are other more complex natural effects, which depend at the same time on the influence of heat, and of attractive forces thus, the variations of temperatures which the movements of the sun occasion in the atmosphere and in the ocean, change continually the density of the different parts of the air and the waters The effect of the forces which these masses obey is modified at every instant by a new distribution of heat, and it cannot be doubted that this cause produces the regular winds, and the chief currents of the sea, the solar and lunar attractions occasioning in the atmosphere effects but slightly sensible, and not general displacements It was therefore necessary, in order to submit these grand phenomena to calculation, to discover the mathematical laws of

ies a

reg) be

regarded as arbitrary

trigonometric functions

Several problems of mechanics present analogous results, such as the isochronism of oscillations, the multiple resonance of sonorous bodies Common experiments had made these results remarked, and analysis afterwards demonstrated their true cause As to those results which depend on changes of temperature, they could not have been recognised except by very exact experiments, but mathematical analysis has outrun observation, it has supplemented our senses, and has made us in a manner witnesses of regular and harmonic vibrations in the interior of bodies

20 These considerations present a singular example of the relations which exist between the abstract science of numbers and natural causes

When a metal bar is exposed at one end to the constant action of a source of heat, and every point of it has attained its highest temperature, the system of fixed temperatures corresponds exactly to a table of logarithms, the numbers are the elevations of thermometers placed at the different points, and the logarithms are the distances of these points from the source In general, heat distributes itself in the interior of solids according to a simple law expressed by a partial differential equation common to physical problems of different order The irradiation of heat has an evident relation to the tables of sines, for the *rays which depart from the same point of a heated surface, differ very much* from each other, and their intensity is rigorously proportional to the sine of the angle which the direction of each ray makes with the element of surface

If we could observe the changes of temperature for every instant at every point of a solid homogeneous mass, we should discover in these series of observations the properties of recurring series, as of sines and logarithms, they would be noticed for example in the diurnal or annual variations of temperature of different points of the earth near its surface

We should recognise again the same results and all the chief elements of general analysis in the vibrations of elastic media, in the properties of lines or of curved surfaces, in the movements of the stars, and those of light or of fluids Thus the functions obtained by successive differentiations, which are employed in the development of infinite series and in the solution of numerical equations, correspond also to physical properties The first of these functions, or the fluxion properly so called, expresses in geometry the inclination of the tangent of a curved line, and in dynamics the velocity of a moving body when the motion varies, in the theory of heat it measures the quantity of heat which flows at each point of a body across a given surface Mathematical analysis has therefore necessary relations with sensible phenomena, its object is not created by human intelligence, it is a pre-existent element of the universal order, and is not in any way contingent or fortuitous, it is imprinted throughout all nature

21 Observations more exact and more varied will presently ascertain

result from the influence of heat combined with that of gravity The same principles will serve to measure the conductivities, proper or relative, of different bodies, and their specific capacities, to distinguish all the causes which modify the emission of heat at the surface of solids, and to perfect thermometric instruments

The theory of heat will always attract the attention of mathematicians, by the rigorous exactness of its elements and the analytical difficulties peculiar to it, and above all by the extent and usefulness of its applications, for all its consequences concern at the same time general physics, the operations of the arts, domestic uses and civil economy

SECTION II *Preliminary Definitions and General Notions*

22 Of the nature of heat uncertain hypotheses only could be formed, but the knowledge of the mathematical laws to which its effects are subject is independent of all hypothesis it requires only an attentive examination of the chief facts which common observations have indicated, and which have been confirmed by exact experiments

It is necessary then to set forth, in the first place, the general results of observation, to give exact definitions of all the elements of the analysis and to establish the principles upon which this analysis ought to be founded

The action of heat tends to expand all bodies, solid liquid or gaseous, this is the property which gives evidence of its presence Solids and liquids increase in volume, in most cases, if the quantity of heat which they contain increases, they contract if it diminishes

When all the parts of a solid homogeneous body, for example those of a mass of metal, are equally heated, and preserve without any change the same quantity of heat, they have also and retain the same density This state is expressed by saying that throughout the whole extent of the mass the molecules have a common and permanent temperature

23 The thermometer is a body whose smallest changes of volume can be appreciated it serves to measure temperatures by the dilatation of a fluid or of air We assume the construction, use and properties of this instrument to be accurately known The temperature of a body equally heated in every part, and which keeps its heat, is that which the thermometer indicates when it is and remains in *perfect contact* with the body in question

Perfect contact is when the thermometer is completely immersed in a fluid mass, and, in general, when there is no point of the external surface of the instrument which is not touched by one of the points of the solid or liquid mass whose temperature is to be measured In experiments it is not always necessary that this condition should be rigorously observed, but it ought to be assumed in order to make the definition exact

24 Two fixed temperatures are determined on, namely the temperature of melting ice which is denoted by 0, and the temperature of boiling water which we will denote by 1 the water is supposed to be boiling under an atmospheric pressure represented by a certain height of the barometer (76 centimetres), the mercury of the barometer being at the temperature 0

25 Different quantities of heat are measured by determining how many times they contain a fixed quantity which is taken as the unit Suppose a mass of ice having a definite weight (a kilogramme) to be at temperature 0, and to

be converted into water at the same temperature 0 by the addition of a certain quantity of heat the quantity of heat thus added is taken as the unit of measure Hence the quantity of heat expressed by a number C contains C times the quantity required to melt a kilogramme of ice at the temperature zero into a mass of water at the same zero temperature

26 To raise a metallic mass having a certain weight, a kilogramme of iron for example, from the temperature 0 to the temperature 1, a new quantity of heat must be added to that which is already contained in the mass The number C which denotes this additional quantity of heat, is the specific capacity of iron for heat, the number C has very different values for different substances

27 If a body of definite nature and weight (a kilogramme of mercury) occupies a volume V at temperature 0, it will occupy a greater volume $V+\Delta$,

quantity C, a quantity zC is added (z being a number positive or negative) the new volume will be $V+\delta$ instead of $V+\Delta$ Now experiments shew that if z is equal to $\frac{1}{2}$, the increa

in general the value

28 The ratio z of

same as the ratio of the two increments of volume δ and Δ, is that which is

29 The increments of volume of bodies are in general proportional to the increments of the quantities of heat which produce the dilatations, but it must be remarked that this proportion is exact only in the case where the bodies in question are subjected to temperatures remote from those which determine their change of state The application of these results to all liquids must not be relied on, and with respect to water in particular, dilatations do not always follow augmentations of heat

In general the temperatures are numbers proportional to the quantities of heat added, and in the cases considered by us, these numbers are proportional also to the increments of volume

30 Suppose that a body bounded by a plane surface having a certain area (a square metre) is maintained in any manner whatever at constant temperature 1, common to all its points, and that the surface in question is in contact

surface in a definite time (a minute)

This amount h, of a flow continuous and always similar to itself, which takes place at a unit of surface at a fixed temperature, is the measure of the external conducibility of the body, that is to say, of the facility with which its surface

veloc-

immuni-

cated to the medium would vary also the same would happen if the density of the medium were increased

31 If the excess of the constant temperature of the body over the temperature of surrounding bodies instead of being equal to 1 as has been supposed had a less value the quantity of heat dissipated would be less than h The result of observation is as we shall see presently that this quantity of heat lost may be regarded as sensibly proportional to the excess of the temperature of the body over that of the air and surrounding bodies Hence the quantity h having been determined by one experiment in which the surface heated is at temperature 1, and the medium at temperature 0 we conclude that hz would be the quantity if the temperature of the surface were z, all the other circumstances remaining the same This result must be admitted when z is a small fraction

32 The value h of the quantity of heat which is dispersed across a heated surface is different for different bodies and it varies for the same body according to the different states of the surface The effect of irradiation diminishes as the surface becomes more polished so that by destroying the polish of the surface the value of h is considerably increased A heated metallic body will be more quickly cooled if its external surface is covered with a black coating such as will entirely tarnish its metallic lustre

33 The rays of heat which escape from the surface of a body pass freely through spaces void of air, they are propagated also in atmospheric air their directions are not disturbed by agitations in the intervening air they can be reflected by metal mirrors and collected at their foci Bodies at a high temperature when plunged into a liquid heat directly only those parts of the mass

considerable distances whether it be that part of these rays traverses freely the layers of air or whether these layers transmit the rays suddenly without altering their direction

34 When the heated body is placed in air which is maintained at a sensibly constant temperature the heat communicated to the air makes the layer of the fluid nearest to the surface of the body lighter this layer rises more quickly the more intensely it is heated and is replaced by another mass of cool air A current is thus established in the air whose direction is vertical and whose

if the body were exposed to a current of air at a constant velocity

35 When bodies are sufficiently heated to diffuse a vivid light part of their radiant heat mixed with that light can traverse transparent solids or liquids and is subject to the force which produces refraction The quantity of heat

It becomes less as the bodies are less inflamed it is

they may be

et heat which

36 We have taken as the measure of the external conductivity of a solid body a coefficient h, which denotes the quantity of heat which would pass, in a definite time (a minute), from the surface of this body, into atmospheric air, supposing that the surface had a definite extent (a square metre), that the constant temperature of the body was 1, and that of the air 0, and that the heated surface was exposed to a current of air of a given invariable velocity This value of h is determined by observation The quantity of heat expressed by the coefficient is composed of two distinct parts which cannot be measured except by very exact experiments One is the heat communicated by way of contact to the surrounding air the other, much less than the first, is the radiant heat emitted We must assume, in our first investigations that the quan- [illegible]

property [illegible] is their conductivity pr[illegible]re after having treated o[illegible]iquid substances possess also the property of transmitting heat from molecule to molecule and *the numerical value of their conductivity varies according to the nature of the* substances but this effect is observed with difficulty in liquids since their molecules change places on change of temperature The propagation of heat in them depends chiefly on this continual displacement, in all cases where the lower parts of the mass are most exposed to the action of the source of heat [illegible]

increase of temperature does not diminish the volume, as is indeed noticed in [illegible]

different bodies placed in the same region all of whose parts are and remain [illegible] ant temperature [illegible] body m be placed in perfect contact with the mass M, it will assume the common temperature a

In reality this result would not strictly occur except after an infinite time [illegible]

sively applied to the different bodies m, n, p, q, r would indicate the same temperature

39 The effect in question is independent of contact and would still occur, if every part of the body m were enclosed in the solid M, as in an enclosure, [illegible]

any point of the internal surface of the enclosure, it would acquire the common *temperature a, or rather, it would preserve it if it had it already* The result would be the same for all the other bodies *n*, *p*, *q*, *r*, whether they were placed separately or all together in the same enclosure, and whatever also their substance and form might be

40 Of all modes of presenting to ourselves the action of heat, that which seems simplest and most conformable to observation, consists in comparing this action to that of light Molecules separated from one another reciprocally communicate, across empty space, their rays of heat, just as shining bodies transmit their light

If within an enclosure closed in all directions, and maintained by some external cause at a fixed temperature *a*, we suppose different bodies to be placed without touching any part of the boundary, different effects will be observed according as the bodies, introduced into this space free from air, are more or less heated If, in the first instance, we insert only one of these bodies, at the same temperature as the enclosure, it will send from all points of its surface as much heat as it receives from the solid which surrounds it, and is maintained in its original state by this exchange of equal quantities

If we insert a second body whose temperature *b* is less than *a*, it will at first receive from the surfaces which surround it on all sides without touching it, a quantity of heat greater than that which it gives out it will be heated more and more and will absorb through its surface more heat than in the first instance

The initial temperature *b* continually rising, will approach without ceasing the fixed temperature *a*, so that after a certain time the difference will be almost insensible The effect would be opposite if we placed within the same enclosure a third body whose temperature was greater than *a*

41 All bodies have the property of emitting heat through their surface, the hotter they are the more they emit, the intensity of the emitted rays changes very considerably with the state of the surface

42 *Every surface which receives rays of heat from surrounding bodies* reflects part and admits the rest the heat which is not reflected, but introduced through the surface, accumulates within the solid, and so long as it exceeds the quantity dissipated by irradiation the temperature rises

43 The rays which tend to go out of heated bodies are arrested at the surface *by a force which reflects part of them into the interior of the mass* The cause which hinders the incident rays from traversing the surface, and which divides these rays into two parts, of which one is reflected and the other admitted, acts in the same manner on the rays which are directed from the interior of the body towards external space

If by modifying the state of the surface we increase the force by which it reflects the incident rays, we increase at the same time the power which it has of reflecting towards the interior of the body rays which are tending to go out The incident rays introduced into the mass, and the rays emitted through the surface, are equally diminished in quantity

44 *If within the enclosure above mentioned a number of bodies were placed* at the same time, separate from each other and unequally heated, they would receive and transmit rays of heat so that at each exchange their temperatures would continually vary, and would all tend to become equal to the fixed temperature of the enclosure

This effect is precisely the same as that which occurs when heat is propagated within solid bodies for the molecules which compose these bodies are separated by spaces void of air and have the property of receiving accumulating and emitting heat Each of them sends out rays on all sides and at the same time receives other rays from the molecules which surround it

45 The heat given out by a point situated in the interior of a solid mass can pass directly to an extremely small distance only, it is we may say intercepted by the nearest particles these particles only receive the heat directly and act on more distant points It is different with gaseous fluids the direct effects of radiation become sensible in them at very considerable distances

46 Thus the heat which escapes in all directions from a part of the surface of a solid passes on in air to very distant points but is emitted only by those molecules of the body which are extremely near the surface A point of a heated mass situated at a very small distance from the plane superficies which separates the mass from external space sends to that space an infinity of rays, but they do not all arrive there they are diminished by all that quantity of heat which is arrested by the intermediate molecules of the solid The part of

The same consequences apply to all the points which are near enough to the surface to take part in the emission of heat from which it necessarily follows that the whole quantity of heat which escapes from the surface in the normal direction is very much greater than that whose direction is oblique We have submitted this question to calculation and our analysis proves that the intensity of the ray is proportional to the sine of the angle which the ray makes with the element of surface Experiments had already indicated a similar result

at a constant temperature would indicate a temperature incomparably greater than that of the enclosure Bodies placed within this enclosure would not take a common temperature as is always noticed the temperature acquired by them would depend on the place which they occupied or on their form or on the forms of neighbouring bodies

The same results would be observed or other effects equally opposed to common experience if between the rays which escape from the same point any other relations were admitted different from those which we have enunciated We have recognised this law as the only one compatible with the general fact of the equilibrium of radiant heat

48 If a space free from air is bounded on all sides by a solid enclosure whose parts are maintained at a common and constant temperature a and if a thermometer having the actual temperature a is placed at any point whatever of the space its temperature will continue without any change It will receive

If now between the thermometer and a part of the surface of the enclosure a body M be placed whose temperature is a, the thermometer will cease to receive rays from one part of the inner surface, but the rays will be replaced by those which it will receive from the interposed body M An easy calculation proves that the compensation is exact, so that the state of the thermometer will be unchanged It is not the same if the temperature of the body M is different from that of the enclosure When it is greater, the rays which the interposed body M sends to the thermometer and which replace the intercepted rays convey more heat than the latter, the temperature of the thermometer must therefore rise

If, on the contrary, the intervening body has a temperature less than a, that of the thermometer must fall, for the rays which this body intercepts are replaced by those which it gives out, that is to say, by rays cooler than those of the enclosure, thus the thermometer does not receive all the heat necessary to maintain its temperature a

49 Up to this point abstraction has been made of the power which all surfaces have of reflecting part of the rays which are sent to them If this property were disregarded we should have only a very incomplete idea of the equilibrium of radiant heat

Suppose then that on the inner surface of the enclosure, maintained at a constant temperature, there is a portion which enjoys, in a certain degree, the power in question, each point of the reflecting surface will send into space two kinds of rays, the one go out from the very interior of the substance of which the enclosure is formed, the others are merely reflected by the same surface against which they had been sent But at the same time that the surface repels on the outside part of the incident rays, it retains in the inside part of its own rays In this respect an exact compensation is established, that is to say, every one of its own rays which the surface hinders from going out is replaced by a reflected ray of equal intensity

The same result would happen, if the power of reflecting rays affected in any degree whatever other parts of the enclosure, or the surface of bodies placed within the same space and already at the common temperature

Thus the reflection of heat does not disturb the equilibrium of temperatures, and does not introduce, whilst that equilibrium exists, any change in the law according to which the intensity of rays which leave the same point decreases proportionally to the sine of the angle of emission

50 Suppose that in the same enclosure, all of whose parts maintain the temperature a, we place an isolated body M, and a polished metal surface R, which, turning its concavity towards the body, reflects great part of the rays which it received from the body, if we place a thermometer between the body M and the reflecting surface R, at the focus of this mirror, three different effects will be observed according as the temperature of the body M is equal to the common temperature a, or is greater or less

In the first case, the thermometer preserves the temperature a, it receives 1°, rays of heat from all parts of the enclosure not hidden from it by the body M or by the mirror, 2°, rays given out by the body, 3°, those which the surface R sends out to the focus, whether they come from the mass of the mirror itself, or whether its surface has simply reflected them, and amongst the last we may distinguish between those which have been sent to the mirror by the mass M, and those which it has received from the enclosure All the rays in

question proceed from surfaces which, by hypothesis, have a common temperature a, so that the thermometer is precisely in the same state as if the space bounded by the enclosure contained no other body but itself

In the second case, the thermometer placed between the heated body M and

reflected upon the thermometer, contain more heat than in the first case The other difference depends on the fact that the rays sent directly by the body M to the thermometer contain more heat than formerly Both causes, and chiefly the first, assist in raising the temperature of the thermometer

In the third case, that is to say, when the temperature of the mass M is less

hypothesis, that is to say, those which, being sent out by the body M, are reflected by the mirror upon the thermometer, and those which the same body M sends to it directly Thus the thermometer does not receive all the heat which it requires to preserve its original temperature a It gives out more heat than it receives It is inevitable then that its temperature must fall to the point at which the rays which it receives suffice to compensate those which it loses This last effect is what is called the reflection of cold and which, properly speaking, *consists in the reflection of too feeble heat The mirror intercepts* a certain quantity of heat, and replaces it by a less quantity

51 If in the enclosure, maintained at a constant temperature a, a body M be placed, whose temperature a' is less than a, the presence of this body will lower the thermometer exposed to its rays, and we may remark that the rays sent to the thermometer from the surface of the body M, are in general of two kinds, namely, those which come from inside the mass M, and those which, coming from different parts of the enclosure, meet the surface M and are reflected upon the thermometer The latter rays have the common temperature a, but those which belong to the body M contain less heat, and these are the rays which cool the thermometer If now, by changing the state of the

M gives out a greater quantity of its own rays and reflects a less quantity of the rays which it receives from the enclosure, that is to say, these last rays, which have the common temperature, are in part replaced by cooler rays Hence the thermometer no longer receives so much heat as formerly.

If, independently of the change in the surface of the body M, we place a metal mirror adapted to reflect upon the thermometer the rays which have left M, the temperature will assume a value a''' less than a'' The mirror, in

and are reflected upon the thermometer The last rays have a temperature less than a, hence the thermometer no longer receives so much heat as it received before the mirror was set up

Lastly, if we proceed to change also the state of the surface of the mirror, and by giving it a more perfect polish increase its power of reflecting heat the thermometer will fall still lower In fact all the conditions exist which occurred in the preceding case Only *it happens that the mirror gives out a less quantity of its own rays*, and replaces them by those which it reflects Now, amongst these last rays all those which proceed from the interior of the mass M are less intense than *if they had come from the interior of the metal mirror*, hence the thermometer receives still less heat than formerly it will assume therefore a temperature a ′ less than a'''

By the same principles all the known facts of the radiation of heat or of cold are easily explained

52 The effects of heat can by no means be compared with those of an elastic fluid *whose molecules are at rest*

It would be useless to attempt to deduce from this hypothesis the laws of propagation which we have explained in this work and which all experience has confirmed *The free state of heat is the same as that of light, the active* state of this element is then entirely different from that of gaseous substances Heat acts in the same manner in a vacuum in elastic fluids and in liquid or *solid masses it is propagated only by way of radiation, but its sensible effects* differ according to the nature of bodies

53 Heat is the origin of all elasticity it is the repulsive force which preserves *the form of solid masses* and the *volume of liquids In solid masses*, neighbouring molecules would yield to their mutual attraction, if its effect were not destroyed by the heat which separates them

This elastic force is greater according as the temperature is higher which is the reason why bodies dilate or contract when their temperature is raised or lowered

54 The equilibrium which exists in the interior of a solid mass between the *repulsive force of heat and the molecular attraction* is stable that is to say, it re-establishes itself when disturbed by an accidental cause If the molecules are arranged at distances proper for equilibrium, and if an external force begins to increase this distance without any change of temperature the effect of attraction begins by surpassing that of heat and brings back the molecules to their original position, after a multitude of oscillations which become less and less sensible

A similar effect is exerted in the opposite sense when a mechanical cause *diminishes the primitive distance of the molecules* such *is the origin of the* vibrations of sonorous or flexible bodies and of all the effects of their elasticity

55 In the liquid or gaseous state of matter, the external pressure is additional or supplementary to the molecular attraction, and *acting on the surface*, does not oppose change of form but only change of the volume occupied Analytical investigation will best shew how the repulsive force of heat, opposed to the attraction of the molecules or to the external *pressure assists in* the composition of bodies, solid or liquid formed of one or more elements and determines the elastic properties of gaseous fluids, but these researches do not belong to the *object before us and appear in dynamic theories.*

56 It cannot be doubted that the mode of action of heat always consists like that of light, in the reciprocal communication of rays, and this explana-

tion is at the present time adopted by the majority of physicists, but it is not necessary to consider the phenomena under this aspect in order to establish the theory of heat In the course of this work it will be seen how the laws of equilibrium and propagation of radiant heat, in solid or liquid masses, can be rigorously demonstrated, independently of any physical explanation, as the necessary consequences of common observations

SECTION III *Principle of the Communication of Heat*

57 We now proceed to examine what experiments teach us concerning the communication of heat

If two equal molecules are formed of the same substance and have the same temperature, each of them receives from the other as much heat as it gives up to it, their mutual action may then be regarded as null, since the result of this action can bring about no change in the state of the molecules If, on the contrary, the first is hotter than the second, it sends to it more heat than it receives from it, the result of the mutual action is the difference of these two quantities of heat In all cases we make abstraction of the two equal quantities of heat which any two material points reciprocally give up, we conceive that the point most heated acts only on the other, and that, in virtue of this action, the first loses a certain quantity of heat which is acquired by the second Thus the action of the two molecules, or the quantity of heat which the hottest communicates to the other, is the difference of the two quantities which they give up to each other

58 Suppose that we place in air a solid homogeneous body, whose different points have unequal actual temperatures, each of the molecules of which the body is composed will begin to receive heat from those which are at extremely small distances, or will communicate it to them This action exerted during the same instant between all points of the mass, will produce an infinitesimal resultant change in all the temperatures the solid will experience at each instant similar effects, so that the variations of temperature will become more and more sensible

Consider only the system of two molecules, m and n, equal and extremely

the first instant

The quantity of heat communicated by the point n to the point m depends on the duration of the instant, on the very small distance between these

which one of the molecules receives from the other is proportional to the difference of temperature of the two molecules Thus the quantity would be

action of n on m is always just as much greater as there is a greater difference

between the temperatures of the two points it is null, if the temperatures are equal but if the molecule n contains more heat than the equal molecule m, that is to say, if the temperature of m being v, that of n is $v+\Delta$, a portion of the exceeding heat will pass from n to m Now, if the excess of heat were double, or, which is the same thing, if the temperature of n were $v+2\Delta$, the exceeding heat *would* be composed of two equal parts corresponding to the two halves of the whole difference of temperature 2Δ, each of these parts would have its proper effect as if it alone existed thus the quantity of heat communicated by n to m *would* be twice as great as when the difference of temperature is only Δ This simultaneous action of the different parts of the exceeding heat is that which constitutes the principle of the communication of heat It follows from it that the sum of the partial actions or the total quantity of heat which m receives from n is porportional to the difference of the two temperatures

59 Denoting by v and v' the temperatures of two equal molecules m and n, by p, their extremely small distance, and by dt, the infinitely small duration of the instant the quantity of heat which m receives from n during this instant will be expressed by $(v'-v)\phi(p)\ dt$ We denote by $\phi(p)$ a certain function of the distance p which, in solid bodies and in liquids, becomes nothing when p has a sensible magnitude The function is the same for every point of the same given substance, it varies with the nature of the substance

60 The quantity of heat which bodies lose through their surface is subject to the same principle If we denote by σ the area finite or infinitely small of the surface all of whose points have the temperature v, and if a represents the temperature of the atmospheric air, the coefficient h being the measure of the external conducibility, we shall have $\sigma h(v-a)dt$ as the expression for the quantity of heat which this surface σ transmits to the air during the instant dt

When the two molecules, one of which transmits to the other a certain quantity of heat, belong to the same solid, the exact expression for the heat communicated is that which we have given in the preceding article, and since the molecules are extremely near, the difference of the temperatures is extremely small It is not the same when heat passes from a solid body into a gaseous medium But the experiments teach us that if the difference is a quantity sufficiently small the heat transmitted is sensibly proportional to that difference, and that the number h may, in these first researches be considered as having a constant value, proper to each state of the surface, but independent of the temperature

61 These propositions relative to the quantity of heat communicated have been derived from different observations We see first as an evident consequence of the expressions in question, that if we increased by a common quantity all the initial temperatures of the solid mass, and that of the medium in which it is placed, the successive changes of temperature would be exactly the same as if this increase had not been made Now this result is sensibly in accordance with experiment, it has been admitted by the physicists who first have observed the effects of heat

62 If the medium is maintained at a constant temperature, and if the heated body which is placed in that medium has dimensions sufficiently small for the temperature, whilst falling more and more, to remain sensibly the same at all points of the body, it follows from the same propositions, that a quantity of heat will escape at each instant through the surface of the body proportional

to the excess of its actual temperature over that of the medium Whence it is easy to conclude, as will be seen in the course of this work, that the line whose abscissæ represent the times elapsed, and whose ordinates represent the temperatures corresponding to those times, is a logarithmic curve now, observations also furnish the same result, when the excess of the temperature of the solid over that of the medium is a sufficiently small quantity

63 Suppose the medium to be maintained at the constant temperature 0, and that the initial temperatures of different points a, b, c, d &c of the same mass are α, β, γ, δ &c , that at the end of the first instant they have become α', β', γ', δ' &c , that at the end of the second instant they have become α'', β'', γ'', δ'' &c , and so on We may easily conclude from the propositions enun-

For instance, let us compare the case when the initial temperatures of the points, a, b, c, d &c were α, β, γ, δ &c with that in which they are 2α, 2β, 2γ, 2δ &c , the medium preserving in both cases the temperature 0 In the second

temperatures had been doubled, it would have become $2\alpha'$ The same would be the case with all the other molecules b, c, d, and a similar result would be derived, if the ratio instead of being 2, were any number whatever g It follows then, from the principle of the communication of heat, that if we increase or diminish in any given ratio all the initial temperatures, we increase or diminish in the same ratio all the successive temperatures

This, like the two preceding results, is confirmed by observation It could not have existed if the quantity of heat which passes from one molecule to another had not been, *actually, proportional to the difference of the temperatures*

necessary first to know all the rigorous consequences of this proposition, by it we determine the chief part of the quantities which are the object of the problem By comparing then the calculated values with those given by numerous and very exact experiments, we can easily measure the variations of the coefficients, and perfect our first researches

SECTION IV *On the Uniform and Linear Movement of Heat*

65 We shall consider in the first place the uniform movement of heat in the simplest case which is that of an infinite solid enclosed between two parallel planes

We suppose a solid body formed of some homogeneous substance to be enclosed between two parallel and infinite planes the lower plane A is maintained by any cause whatever at a constant temperature a we may imagine for example that the mass is prolonged and that the plane A is a section common to the solid and to the enclosed mass and is heated at all its points by a constant source of heat the upper plane B is also maintained by a similar cause at a fixed temperature b whose value is less than that of a the problem is to determine what would be the result of this hypothesis if it were continued for an infinite time

If we suppose the initial temperature of all parts of this body to be b it is evident that the heat which leaves the source A will be propagated farther and farther and will raise the temperature of the molecules included between the two planes but the temperature of the upper plane being unable according to hypothesis to rise above b the heat will be dispersed within the cooler mass contact with which keeps the plane B at the constant temperature b The system of temperatures will tend more and more to a final state which it will never attain but which would have the property as we shall proceed to show of existing and keeping itself up without any change if it were once formed

In the final and fixed state which we are considering the permanent temperature of a point of the solid is evidently the same at all points of the same section parallel to the base and we shall prove that this fixed temperature common to all the points of an intermediate section decreases in arithmetic progression from the base to the upper plane that is to say if we represent the constant temperatures a and b by the ordinates $A\alpha$ and $B\beta$ (see Fig 1) raised

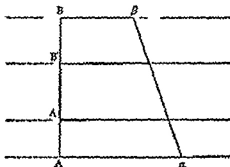


Fig 1

perpendicularly to the distance AB between the two planes the fixed temperatures of the intermediate layers will be represented by the ordinates of the straight line $\alpha\beta$ which joins the extremities α and β thus denoting by z the height of an intermediate section or its perpendicular distance from the plane A by e the whole height or distance AB, and by v the temperature of the section whose height is z we must have the equation $v=a+\frac{b-a}{e}z$

In fact if the temperatures were at first established in accordance with this

law, and if the extreme surfaces A and B were always kept at the temperatures a and b, no change would happen in the state of the solid To convince ourselves of this, it will be sufficient to compare the quantity of heat which would traverse an intermediate section A' with that which, during the same time, would traverse another section B'

Bearing in mind that the final state of the solid is formed and continues we see that the part of the mass which is below and plane A' must communicate heat to the part which is above that plane, since this second part is cooler than the first

Imagine two points of the solid, m and m', very near to each other, and placed in any manner whatever, the one m below the plane A', and the other m' above this plane, to be exerting their action during an infinitely small instant m the hottest point will communicate to m' a certain quantity of heat which will cross the plane A' Let x, y, z be the rectangular coordinates of the point m, and x', y', z' the coordinates of the point m' consider also two other points n and n' very near to each other, and situated with respect to the plane B', in the same manner in which m and m' are placed with respect to the plane A' that is to say, denoting by ζ the perpendicular distance of the two sections A' and B', the coordinates of the point n will be x, y, $z+\zeta$ and those of the point n', x', y', $z'+\zeta$, the two distances mm' and nn' will be equal further the difference of the temperature v of the point m above the temperature v' of the point m' will be the same as the difference of temperature of the two points n and n' In fact the former difference will be determined by substituting first z and then z' in the general equation

$$v = a + \frac{b-a}{e} z,$$

and subtracting the second equation from the first, whence the result $v-v' = \frac{b-a}{e}(z-z')$ We shall then find, by the substitution of $z+\zeta$ and $z'+\zeta$, that the excess of temperature of the point n over that of the point n' is also expressed by

$$\frac{b-a}{e}(z-z')$$

It follows from this that the quantity of heat sent by the point m to the point m' will be the same as the quantity of heat sent by the point n to the point n', for all the elements which concur in determining this quantity of transmitted heat are the same

It is manifest that we can apply the same reasoning to every system of two molecules which communicate heat to each other across the section A' or the section B', whence, if we could sum up the whole quantity of heat which flows, during the same instant, across the section A' or the section B', we should find this quantity to be the same for both sections

From this it follows that the part of the solid included between A' and B'

which it has at present Thus, it has been rigorously demonstrated that the state of the prism will continue to exist just as it was at first

Hence, the permanent temperatures of different sections of a solid enclosed between two parallel infinite planes, are represented by the ordinates of a

straight line $\alpha\beta$, and satisfy the linear equation $v=a+\frac{b-a}{e}z$

66 By what *precedes we see distinctly what constitutes the propagation of* heat in a solid enclosed between two parallel and infinite planes, each of which *is maintained at a constant temperature Heat penetrates the mass gradually* across the lower plane the temperatures of the intermediate sections are *raised, but can never exceed nor even quite attain a certain limit which they* approach nearer and nearer this limit or final temperature is different for *different intermediate layers, and decreases in arithmetic progression from the* fixed temperature of the lower plane to the fixed temperature of the upper plane

The final temperatures are those which would have to be given to the solid in order that its state might be permanent, the variable state which precedes it may also be submitted to analysis, as we shall see presently but we are now considering only the system of final and permanent temperatures *In the last* state, during each division of time, across a section parallel to the base, or a definite portion of that section, a certain quantity of heat flows, which is constant if the divisions of time are equal This uniform flow is the same for all the intermediate sections, it is equal to that which proceeds from the source, and to that which is lost during the same time, at the upper surface of the solid, by virtue of the cause which keeps the temperature constant

67 The problem now is to measure that quantity of heat which is propagated uniformly within the solid, during a given time across a definite part of a section parallel to the base it depends, as we shall see, on the two extreme temperatures a and b, and on the distance e between the two sides ,
it would vary if any one of these elements be
ing the same Suppose a second
first, and enclosed betwe ... perpendicular

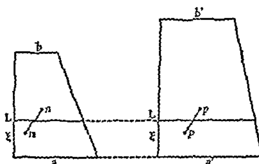


Fig 2

distance is e' (see Fig 2) the lower side is maintained at a fixed temperature a', and the upper side at the fixed temperature b', both solids are considered to be in that final and permanent state which has the property of maintaining itself as soon as it has been formed Thus the law of the temperatures is expressed for the first body by the equation $v=a+\frac{b-a}{e}z$, and for the second, by the equation $u=a'+\frac{b'-a'}{e'}z$, v in the first solid, and u in the second, being the temperature of the section whose height is z

This arranged, we will compare the quantity of heat which during the unit of time traverses a unit of area taken on an intermediate section L of the first solid,
the se
that i
cons
low
of n
than z

We shall consider also in the second solid the instantaneous action of two points p and p', which are situated, with respect to the section L', in the same manner as the points n and n' with respect to the section L of the first solid Thus the same co-ordinates x, y, z, and x', y', z' referred to three rectangular axes in the second body, will fix also the position of the points p and p'

Now, the distance from the point n to the point n' is equal to the distance from the point p to the point p', and since the two bodies are formed of the same substance, we conclude, according to the principle of the communication of heat that the action of n on n', or the quantity of heat given by n to n', and the action of p on p', are to each other in the same ratio as the differences of the temperature $v-v'$ and $u-u'$

Substituting v and then v' in the equation which belongs to the first solid, and subtracting we find $v-v'=\frac{b-a}{e}(z-z')$, we have also by means of the second equation $u-u'=\frac{b'-a'}{e}(z-z')$, whence the ratio of the two actions in question is that of $\frac{a-b}{e}$ to $\frac{a'-b'}{e'}$

We may now imagine many other systems of two molecules, the first of which sends to the second across the plane L, a certain quantity of heat and each of these systems, chosen in the first solid, may be compared with a homologous system situated in the second, and whose action is exerted across the section L', we can then apply again the previous reasoning to prove that the ratio of the two actions is always that of $\frac{a-b}{e}$ to $\frac{a'-b'}{e'}$

Now, the whole quantity of heat which, during one instant, crosses the section L, results from the simultaneous action of a multitude of systems each of

other in the ratio of $\frac{a-b}{e}$ to $\frac{a'-b'}{e'}$

It is easy then to compare with each other the intensities of the constant *flows of heat which are propagated uniformly* in the two solids, that is to say, the quantities of heat which, during unit of time, cross unit of surface of each of these bodies The ratio of these intensities is that of the two quotients $\frac{a-b}{e}$ and $\frac{a'-b'}{e'}$ If the two quotients are equal the flows are the same, whatever in other respects the values a, b, e, a', b', e', may be, in general, denoting the first flow by F and the second by F', we shall have $\frac{F}{F'}=\frac{a-b}{e}-\frac{a'-b'}{e'}$

68 Suppose that in the second solid, the permanent temperature a' of the lower plane is that of boiling water, 1, that the temperature e' of the upper plane is that of melting ice, 0, that the distance b' *of the two planes is the unit* of measure (a metre), let us denote by K the constant flow of heat which, during unit of time (a minute) would cross unit of surface in this last solid, if it were formed of a given substance, K expressing a certain number of units of heat, that is to say a certain number of times the heat necessary to convert a kilogramme of ice into water we shall have, in general, to determine the constant flow F, in a solid formed of the same substance, the equation $\frac{F}{K} = \frac{a-b}{e}$ or $F = K\frac{a-b}{e}$

The value of F denotes the quantity of heat which, during the unit of time, *passes across a unit of area of the surface taken on a section parallel to the base*

Thus the thermometric state of a solid enclosed between two parallel infinite plane sides whose perpendicular distance is e, and which are maintained at fixed temperatures a and b, is represented by the two equations

$$v = a + \frac{b-a}{e} z, \text{ and } F = K\frac{a-b}{e} \text{ or } F = -K\frac{dv}{dz}$$

The first of these equations expresses the law according to which the temperatures decrease from the lower side to the opposite side, the second indicates the quantity of heat which, during a given time, crosses a definite part of a section parallel to the base

69 We have taken this coefficient K, which enters into the second equation, to be the measure of the specific conducibility of each substance, this number has very different values for different bodies

It represents in general, the quantity of heat which, in a homogeneous solid formed of a given substance and enclosed between two infinite parallel planes, flows, during one minute across a surface of one square metre taken on a section parallel to the extreme planes, supposing that these two planes are maintained one at the temperature of boiling water, the other at the temperature of melting ice, and that all the intermediate planes have acquired and retain a permanent temperature

We might employ another definition of conductivity, since we could estimate the capacity for heat by referring it to unit of volume, instead of referring it to unit of mass All these definitions are equally good provided they are clear and precise

We shall shew presently how to determine by observation the value K of the conducibility or conductibility in different substances

70 In order to establish the equations which we have cited in Article 68 it would not be necessary to suppose the points which exert their action across the planes to be at extremely small distances

The results would still be the same if the distances of these points had any magnitude whatever, they would therefore apply also to the case where the direct action of heat extended within the interior of the mass to very considerable distances, all the circumstances which constitute the hypothesis remaining in other respects the same

We need only suppose that the cause which maintains the temperatures at the surface of the solid, affects not only that part of the mass which is extremely near to the surface, but that *its action extends to a finite depth* The

equation $v=a-\frac{a-b}{e}z$ will still represent in this case the permanent temperatures of the solid The true sense of this proposition is that, if we give to all points of the mass the temperatures expressed by the equation and if besides any cause whatever acting on the two extreme laminæ retained always every one of their molecules at the temperature which the same equation assigns to them, the interior points of the solid would preserve without any change their initial state

If we supposed that the action of a point of the mass could extend to a finite distance ϵ, it would be necessary that the thickness of the extreme laminæ, whose state is maintained by the external cause should be at least equal to ϵ

bound the solid This is always what must be understood by the expression *to maintain the temperature of the surface constant*

71 We proceed further to examine the case in which the same solid would be exposed, at one of its faces, to atmospheric air maintained at a constant temperature

Suppose then that the lower plane preserves the fixed temperature a by

planes being denoted always by e the problem is to determine the final temperatures

represented by the general equation $v=a+\frac{\beta-a}{e}z$, v denoting always the fixed temperature of the section whose height is z The quantity of heat which flows during unit of time across a unit of surface taken on any section whatever is $K\frac{a-\beta}{e}$, *k denoting the interior conducibility*

We must now consider that the upper surface B, whose temperature is β, permits the escape into the air of a certain quantity of heat which must be exactly equal to that which crosses any section whatever L of the solid If it

flow at the surface is therefore equal to that which traverses the solid now, the quantity of heat which escapes during unit of time from unit of surface taken on the plane B, is expressed by $h(\beta-b)$, b being the fixed temperature of the

air, and h the measure of the conducibility of the surface B we must therefore have the equation $K\frac{a-\beta}{e}=h(\beta-b)$ which will determine the value of β

From this may be derived $a-\beta=\frac{he(a-b)}{he+K}$ an equation whose second member is known for the temperatures a and b are given, as are also the quantities h k, e

Introducing this value of $a-\beta$ into the general equation $v=a+\frac{\beta-a}{e}z$ we shall have to express the temperatures of any section of the solid the equation $a-v=\frac{hz(a-b)}{he+K}$ in which known quantities only enter with the corresponding variables v and z

72 So far we have determined the final and permanent state of the temperatures in a solid enclosed between two infinite and parallel plane surfaces maintained at unequal temperatures This first case is properly speaking the case of the linear and uniform propagation of heat, for there is no transfer of he[at] in the plane parallel to the sides of the solid that which trav[erses] ... i formly since the value of the flow is the sam[e] ... i

We will now restate th[e] ... examin[e]... tions a ...

1st I[f] ... e of the solid we erect perpendiculars ... [tem]peratures a and b of the two sides and if we draw the strai[ght] ... which joins the extremities of these two first ordinates all the intermediate temperatures will be proportional to the ordinates of this straight line they are expressed by the general equation $a-v=\frac{a-b}{e}z$ v denoting the temperature of the section whose height is z

2nd The quantity of heat which flows uniformly during unit of time across unit of surface taken on any section whatever parallel to the sides, all other things being equal is directly proportional to the difference $a-b$ of the extreme temperatures and inversely proportional to the distance e which separates these sides The quantity of heat is expressed by $K\frac{a-b}{e}$, or $-K\frac{dv}{dz}$ if we derive from the general equation the value of $\frac{dv}{dz}$ which is constant this uniform flow may always be represented for a given substance and in the solid under examination by the tangent of the angle included between the perpendicular e and the straight line whose ordinates represent the temperatures

3rd One of the extreme surfaces of the solid being submitted always to the temperature a if the other plane is exposed to air maintained at a fixed temperature b the plane in contact with the air acquires, as in the preceding case a fixed temperature β greater than b, and it permits a quantity of heat to escape into the air across unit of surface during unit of time which is expressed by $h(\beta-b)$ h denoting the external conducibility of the plane

The same flow of heat $h(\beta-b)$ is equal to that which traverses the prism and whose value is $K(a-\beta)$ we have therefore the equation $h(\beta-b)=K\frac{a-\beta}{e}$, which gives the value of β

SECTION V *Law of the Permanent Temperatures in a Prism of Small Thickness*

73 We shall easily apply the principles which have just been explained to the following problem, very simple in itself, but one whose solution it is important to base on exact theory

A metal bar, whose form is that of a rectangular parallelepiped infinite in length, is exposed to the action of a source of heat which produces a constant temperature at all points of its extremity A It is required to determine the fixed temperatures at the different sections of the bar

The section perpendicular to the axis is supposed to be a square whose side $2l$ is so small that we may without sensible error consider the temperatures to be equal at different points of the same section The air in which the bar is placed is maintained at a constant temperature 0, and carried away by a current with uniform velocity

Inside the solid, heat will pass successively all parts situated to the right or left (*pro re nata*) of the source, and not exposed directly to its action they will be heated more and more, but the temperature of each point will not increase beyond a certain limit This maximum temperature is not the same

system of temperatures varies continually, and approaches more and more to a fixed state, which is that which we consider This final state is kept up of itself when it has once been formed In order that the system of temperatures may be permanent it is necessary that the quantity of heat which, during unit of time, crosses a section made at a distance x from the origin, should balance exactly all the heat which, during the same time escapes through that part of the external surface of the prism which is situated to the right of the same section The lamina whose thickness is dx, and whose external surface is $8l dx$, allows the escape into the air, during unit of time, of a quantity of heat expressed by $8hlv\,dx$, h being the measure of the external conducibility of the prism Hence taking the integral $\int 8hlv\,dx$ from $x=0$ to $x=\infty$, we shall find the quantity of heat which escapes from the whole surface of the bar during unit of time, and if we take the same integral from $x=0$ to $x=x$, we shall have the quantity of heat lost through the part of the surface included between the source of heat and the section made at the distance x Denoting the first integral by C, whose value is constant, and the variable value of the second by $\int 8hlv\,dx$, the difference $C-\int 8hlv\,dx$ will express the whole quantity of heat which escapes into the air across the part of the surface situated to the right of

$-4l^2K\frac{dv}{dx}$, K being the specific internal conductivity we must therefore have

the equation $$-4l^2K\frac{dv}{dx} = C - \int 8hlv\,dx,$$

whence $$Kl\frac{d^2v}{dx^2} = 2hv$$

74 We should obtain the same result by considering the equilibrium of heat in a single lamina infinitely thin enclosed between two sections at distances x and $x+dx$ In fact the quantity of heat which during unit of time crosses the first section situated at distance x is $-4l^2K\frac{dv}{dx}$ To find that which flows during the same time across the successive section situated at distance $x+dx$, we must in the preceding expression change x into $x+dx$, which gives $-4l^2K\left[\frac{dv}{dx}+d\left(\frac{dv}{dx}\right)\right]$ If we subtract the second expression from the first we shall find how much heat is acquired by the lamina bounded by these two sections during unit of time and since the state of the lamina is permanent it follows that all the heat acquired is dispersed into the air across the external surface $8ldx$ of the same lamina now the last quantity of heat is $8hlvdx$ we shall obtain therefore the same equation

$$8hlvdx - 4l^2Kd\left(\frac{dv}{dx}\right) \quad \text{whence} \quad \frac{d^2v}{dx^2} = \frac{2h}{Kl}v$$

75 In whatever manner this equation is formed it is necessary to remark that the quantity of heat which passes into the lamina whose thickness is dx, has a finite value and that its exact expression is $-4l^2K\frac{dv}{dx}$ The lamina being enclosed between two surfaces the first of which has a temperature v and the second a lower temperature v' we see that the quantity of heat which it receives through the first surface depends on the difference $v-v'$, and is proportional to it but this remark is not sufficient to complete the calculation The quantity in question is not a differential it has a finite value since it is equivalent to all the heat which escapes through that part of the external surface of the prism which is situated to the right of the section To form an exact idea of it, we must compare the lamina whose thickness is dx, with a solid terminated by two parallel planes whose distance is e and which are maintained at unequal temperatures a and b The quantity of heat which passes into such a prism across the hottest surface is in fact proportional to the difference $a-b$ of the extreme temperatures but it does not depend only on this difference all other things being equal it is less when the prism is thicker and in general it is proportional to $\frac{a-b}{e}$ This is why the quantity of heat which passes through the first surface into the lamina whose thickness is dx, is proportional to $\frac{v-v'}{dx}$

We lay stress on this remark because the neglect of it has been the first obstacle to the establishment of the theory If we did not make a complete analysis of the elements of the problem we should obtain an equation not homogeneous, and *a fortiori*, we should not be able to form the equations which express the movement of heat in more complex cases

It was necessary also to introduce into the calculation the dimensions of the prism, in order that we might not regard, as general, consequences which observation had furnished in a particular case Thus, it was discovered by experiment that a bar of iron, heated at one extremity, could not acquire, at a distance of six feet from the source, a temperature of one degree (octogesimal[1]), for to produce this effect, it would be necessary for the heat of the source to surpass considerably the point of fusion of iron, but this result depends on the thickness of the prism employed If it had been greater, the heat would have been propagated to a greater distance, that is to say, the point of the bar which acquires a fixed temperature of one degree is much more remote from the source when the bar is thicker, all other conditions remaining the

besides a proof will be found in the solution of the problem (Art 78)

76 The integral of the preceding equation is

$$v=Ae^{-x\sqrt{\frac{2h}{Kl}}}+Be^{+x\sqrt{\frac{h}{Kl}}},$$

the constant A, since that is the value of v when x is zero

This law according to which the temperatures decrease is the same as that given by experiment, several physicists have observed the fixed temperatures at different points of a metal bar exposed at its extremity to the constant

peratures being determined by observation, we easily deduce the value of the ratio $\frac{h}{K}$, for, denoting by v_1, v_2 the temperatures corresponding to the distances x_1, x_2, we have

$$\frac{v_1}{v_2}=e^{-(x_1-x_2)\sqrt{\frac{2h}{Kl}}}, \text{ whence } \sqrt{\frac{2h}{K}}=\frac{\log v_1-\log v_2}{x_2-x_1}\sqrt{l}$$

$$v_1=Ae^{-x_1\sqrt{\frac{2h}{Kl}}} \text{ and } v_2=Ae^{-x_2\sqrt{\frac{2h}{Kl}}},$$

x_1,

x_2

of a

section of the first, at a certain distance from the source, will not be equal to

[1] Reaumur's scale of temperature

[2] The conducting power K is not constant, but diminishes as the temperature increases.

the temperature of a section of the second at the same distance from the focus, in order that the fixed temperatures may be equal, the distances must be different If we wish to compare with each other the distances x_1 and x_2 from the origin up to the points which in the two bars attain the same temperature we must equate the second members of these equations and from them we conclude that $\frac{x_1^2}{x_2^2} = \frac{l_1}{l_2}$ Thus the distances in question are to each other as the *square roots of the thicknesses*

79 If two metal bars of equal dimensions but formed of different sub stances, are covered with the same coating which gives them the same external conducibility, and if they are submitted at their extremities to the same temperature, heat will be propagated most easily and to the greatest distance from the origin in that which has the greatest conductivity To compare with each other the distances x_1 and x_2 from the common origin up to the points which acquire the same fixed temperature, we must after denoting the respective conducibilities of the two substances by K_1 and K_2, write the equation

$$e^{-x_1\sqrt{\frac{2h}{K_1l}}} = e^{-x_2\sqrt{\frac{2h}{K_2l}}}, \text{ whence } \frac{x_1^2}{x_2^2} = \frac{K_1}{K_2}$$

Thus the ratio of the two conductivities is that of the squares of the distances from the common origin to the points which attain the same fixed temperature

80 It is easy to ascertain how much heat flows during unit of time through a section of the bar arrived at its fixed state this quantity is expressed by $-4Kl^2\frac{dv}{dx}$, or $4A\sqrt{2Khl^3}\ e^{-x\sqrt{\frac{2h}{Kl}}}$ and if we take its value at the origin, we shall have $4A\sqrt{2Khl^3}$ as the measure of the quantity of heat which passes from the source into the solid during unit of time, thus the expenditure of the source of heat is, all other things being equal, proportional to the square root of the cube of the thickness

We should obtain the same result on taking the integral $\int 8hlv\,dx$ from x nothing to x infinite

SECTION VI *On the Heating of Closed Spaces*

81 We shall again make use of the theorems of Article 72 in the following problem whose solution offers useful applications, it consists in determining the extent of the heating of closed spaces

Imagine a closed space of any form whatever, to be filled with atmospheric air and closed on all sides, and that all parts of the boundary are homogeneous and have a common thickness e, so small that the ratio of the external surface to the internal surface differs little from unity The space which this boundary terminates is heated by a source whose action is constant, for example by means of a surface whose area is σ maintained at a constant temperature α

We consider here only the mean temperature of the air contained in the space, without regard to the unequal distribution of heat in this mass of air, thus we suppose that the existing causes incessantly mingle all the portions of air, and make their temperatures uniform

We see first that the heat which continually leaves the source spreads itself in the surrounding air and penetrates the mass of which the boundary is

formed is partly dispersed at the surface, and passes into the external air, which we suppose to be maintained at a lower and permanent temperature n The inner air is heated more and more the same is the case with the solid boundary the system of temperatures steadily approaches a final state which is the object of the problem and has the property of existing by itself and of being kept up unchanged, provided the surface of the source σ be maintained at the temperature α, and the external air at the temperature n

In the permanent state which we wish to determine the air preserves a fixed temperature m the temperature of the inner surface s of the solid boundary

The degree of heating consists in the excess of the temperature m over n the temperature of the external air, this excess evidently depends on the area σ of the heating surface and on its temperature α, it depends also on the thickness e of the enclosure, on the area s of the surface which bounds it, on the [illegible] which is opposite [illegible] which forms the [illegible] nged, the others [illegible] roblem is

[illegible] which is maintained at a fixed temperature, every prismatic element of the solid enclosed between two opposite portions of these surfaces, and the normals raised round the contour of the bases is therefore in the same state as if it belonged to an infinite solid enclosed between two parallel planes maintained at unequal temperatures All the prismatic elements which compose the boundary touch along their whole length The points of the mass which are equidistant from the inner surface have equal temperatures, to whatever prism they belong, consequently there cannot be any transfer of heat in the direction perpendicular to the length of these prisms The case is, therefore, the same as that of which we have already treated and we must apply to it the linear equations which have been stated in former articles

83 Thus in the permanent state which we are considering the flow of heat which leaves the surface σ during a unit of time is equal to that which during the same time, passes from the surrounding air into the inner surface of the [illegible] also to that which in a unit of time crosses an inter

is contrary to the hypothesis

The first quantity is expressed by $\sigma(\alpha-m)g$, denoting by g the external conducibility of the surface σ, which belongs to the source of heat

The second is $s(m-a)h$, the coefficient h being the measure of the external conducibility of the surface s, which is exposed to the action of the source of heat

The third is $s\frac{a-b}{e}K$, the coefficient K being the measure of the conducibility proper to the homogeneous substance which forms the boundary

The fourth is $s(b-n)H$, denoting by H the external conductivity of the surface s which the heat quits to be dispersed into the air The coefficients h and H may have very unequal values on account of the difference of the state of the two surfaces which bound the enclosure they are supposed to be known, as also the coefficient K we shall have then, to determine the three unknown quantities m, a and b, the three equations

$$\sigma(\alpha-m)g=s(m-a)h,$$

$$\sigma(\alpha-m)g=s\frac{a-b}{e}K,$$

$$\sigma(\alpha-m)g=s(b-n)H$$

84 The value of m is the special object of the problem It may be found by writing the equations in the form

$$m-a=\frac{\sigma}{s}\,\frac{g}{h}\,(\alpha-m),$$

$$a-b=\frac{\sigma}{s}\,\frac{ge}{K}\,(\alpha-m),$$

$$b-n=\frac{\sigma}{s}\,\frac{g}{H}\,(\alpha-m),$$

adding, we have $$m-n=(\alpha-m)\,P,$$

denoting by P the known quantity $\frac{\sigma}{s}\left(\frac{g}{h}+\frac{ge}{K}+\frac{g}{H}\right)$,

whence we conclude

$$m-n=(\alpha-n)\,\frac{P}{1+P}=\frac{(\alpha-n)\frac{\sigma}{s}\left(\frac{g}{h}+\frac{ge}{K}+\frac{g}{H}\right)}{1+\frac{\sigma}{s}\left(\frac{g}{h}+\frac{ge}{K}+\frac{g}{H}\right)}$$

85 The result shews how $m-n$, the extent of the heating depends on given quantities which constitute the hypothesis We will indicate the chief results to be derived from it

1st The extent of the heating $m-n$ is directly proportional to the excess of the temperature of the source over that of the external air

2nd The value of $m-n$ does not depend on the form of the enclosure nor on its volume, but only on the ratio $\frac{\sigma}{s}$ of the surface from which the heat proceeds to the surface which receives it and also on e the thickness of the boundary

If we double σ the surface of the source of heat the extent of the heating does not become double, but increases according to a certain law which the

t is

n a

single element $\frac{g}{h}+\frac{ge}{K}+\frac{g}{H}$, whose value may be determined by observation

If we doubled e the thickness of the boundary, we should have the same result if, in forming it, we employed a substance whose conductivity proper

was twice as great Thus the employment of substances which are bad conductors of heat permits us to make the thickness of the boundary small, the effect which is obtained depends only on the ratio $\frac{e}{K}$

4th If the conducibility K is nothing, we find $m=\alpha$, that is to say, the inner air assumes the temperature of the source the same is the case if H is zero, or h zero These consequences are otherwise evident, since the heat cannot then be dispersed into the external air

5th The values of the quantities g, H, h, K and α, which we supposed known, may be measured by direct experiments, as we shall shew in the sequel, but in the actual problem, it will be sufficient to notice the value of $m-n$ which corresponds to given values of σ and of α, and this value may be used to determine the whole coefficient $\frac{g}{h}+\frac{ge}{K}+\frac{g}{H}$, by means of the equation $m-n=(\alpha-n)\frac{\sigma}{s}p\div\left(1+\frac{\sigma}{s}p\right)$ in which p denotes the coefficient sought We must substitute in this equation, instead of $\frac{\sigma}{s}$ and $\alpha-n$, the values of those quantities, which we suppose given and that of $m-n$ which observation will have made known From it may be derived the value of p, and we may then apply the formula to any number of other cases

6th The coefficient H enters into the value of $m-n$ in the same manner as the coefficient h, consequently the state of the surface, or that of the envelope which covers it, produces the same effect, whether it has reference to the inner or outer surface

We should have considered it useless to take notice of these different consequences, if we were not treating here of entirely new problems, whose results may be of direct use

86 We know that animated bodies retain a temperature sensibly fixed,

the rise of temperature in places where a great number of men are collected together If we there observe the height of the thermometer under given circumstances we shall determine in advance what that height would be, if the number of men assembled in the same space became very much greater

In reality, there are several accessory circumstances which modify the results such as the unequal thickness of the parts of the enclosure, the difference of their aspect, the effects which the outlets produce, the unequal distribution of heat in the air We cannot therefore rigorously apply the rules given by analysis, nevertheless these rules are valuable in themselves, because they contain the true principles of the matter they prevent vague reasonings and useless or confused attempts

87 If the same space were heated by two or more sources of different kinds, or if the first enclosure were itself contained in a second enclosure separated from the first by a mass of air, we might easily determine in like manner the degree of heating and the temperature of the surfaces

If we suppose that, besides the first source σ, there is a second heated surface π, whose constant temperature is β, and external conductivity j, we shall

find, all the other denominations being retained, the following equation

$$m-n=\frac{\frac{(a-n)\sigma g+(\beta-n)\pi j}{s}\left(\frac{e}{K}+\frac{1}{H}+\frac{1}{h}\right)}{1+\frac{\sigma g+\pi j}{s}\left(\frac{e}{K}+\frac{1}{H}+\frac{1}{h}\right)}$$

shall find, p denoting the temperature of the air which surrounds the external surface of the second enclosure, the following equation

$$m-p=\frac{(a-p)P}{1+P}$$

The quantity P represents

$$\frac{\sigma}{s}\left(\frac{g}{h}+\frac{ge}{K}+\frac{g}{H}\right)+\frac{\sigma}{s'}\left(\frac{g}{h'}+\frac{ge'}{K'}+\frac{g}{H'}\right)$$

We should obtain a similar result if we had three or a greater number of successive enclosures, and from this we conclude that these solid envelopes, separated by air, assist very much in increasing the degree of heating, however small their thickness may be

88 To make this remark more evident, we will compare the quantity of heat which escapes from the heated surface, with that which the same body would lose, if the surface which envelopes it were separated from it by an interval filled with air

If the body A be heated by a constant cause, so that its surface preserves a fixed temperature b, the air being maintained at a less temperature a, the quantity of heat which escapes into the air in the unit of time across a unit of surface will be expressed by $h(b-a)$, h being the measure of the external conductivity Hence in order that the mass may preserve a fixed temperature b, it is necessary that the source, whatever it may be, should furnish a quantity of heat equal to $hS(b-a)$, S denoting the area of the surface of the solid

Suppose an extremely thin shell to be detached from the body A and ... the surface

ratio of these quantities

... the fixed temperature of its inner ... We shall ... hrough

its surface, $hS(b-a)$.

As that of the quantity which penetrates the inner surface of the shell, $hS(a'-m)$

As that of the quantity which crosses any section whatever of the same shell, $KS\frac{m-n}{e}$

Lastly, as the expression of the quantity which passes through the outer surface into the air, $hS(n-a)$

All these quantities must be equal, we have therefore the following equations

$$h(n-a)=\frac{K}{e}(m-n),$$
$$h(n-a)=h(a'-m),$$
$$h(n-a)=h(b-a')$$

If moreover we write down the identical equation

$$h(n-a)=h(n-a),$$

and arrange them all under the forms

$$n-a=n-a,$$
$$m-n=\frac{he}{K}(n-a),$$
$$a'-m=n-a,$$
$$b-a'=n-a,$$

we find, on addition,

$$b-a=(n-a)\left(3+\frac{he}{K}\right)$$

The quantity of heat lost by the solid was $hS(b-a)$, when its surface communicated freely with the air, it is now $hS(b-a')$ or $hS(n-a)$, which is equivalent to $hS\frac{b-a}{3+\frac{he}{K}}$

The first quantity is greater than the second in the ratio of $3+\frac{he}{K}$ to 1

In order therefore to maintain at temperature b a solid whose surface communicates directly to the air, more than three times as much heat is necessary than would be required to maintain it at temperature b when its extreme surface is not adherent but separated from the solid by any small interval whatever filled with air

If we suppose the thickness e to be infinitely small, the ratio of the quantities of heat lost will be 3, which would also be the value if K were infinitely great

We can easily account for this result, for the heat being unable to escape into the external air, without penetrating several surfaces, the quantity which flows out must diminish as the number of interposed surfaces increases, but we should have been unable to arrive at any exact judgment in this case, if the

of radiation
rtheless this
heat which

passes directly across the intervening air We shall suppose then, to make the object of the analysis more distinct, that the interval between the surfaces is free from air, and that the heated body is covered by any number whatever of parallel laminæ separated from each other

If the heat which escapes from the solid through its plane superficies maintained at a temperature b expanded itself freely in vacuo and was received by a parallel surface maintained at a less temperature a, the quantity which would be dispersed in unit of time across unit of surface would be proportional to $(b-a)$, the difference of the two constant temperatures this quantity would be represented by $H(b-a)$, H being the value of the relative conducibility which is not the same as h

The source which maintains the solid in its original state must therefore furnish, in every unit of time, a quantity of heat equal to $HS(b-a)$

We must now determine the new value of this expenditure in the case where the surface of the body is covered by several successive laminæ separated by intervals free from air, supposing always that the solid is subject to the action of any external cause whatever which maintains its surface at the temperature b

Imagine the whole system of temperatures to have become fixed, let m_1 be *the temperature of the under surface of the first lamina which is consequently* opposite to that of the solid, let n_1 be the temperature of the upper surface of the same lamina, e its thickness, and K its specific conductivity, denote also by m_1, n_1, m_2, n_2 m_3, n_3, m_4, n_4, &c the temperatures of the under and upper surfaces of the different laminæ, and by K, e, the conductivity and thickness of the same laminæ, lastly suppose all these surfaces to be in a state similar to the surface of the solid, so that the value of the coefficient H is common to them

The quantity of heat which penetrates the under surface of a lamina corresponding to any suffix i is $HS(n_{i-1}-m_i)$, that which crosses this lamina is $\frac{KS}{e}(m_i-n_i)$, and the quantity which escapes from its upper surface is $HS(n_i-m_{i+1})$ These three quantities, and all those which refer to the other laminæ are equal, we may *therefore form the equation by comparing all these* quantities in question with the first of them, which is $HS(b-m_1)$, we shall thus have, denoting the number of laminæ by j

$$b-m_1=b-m_1,$$
$$m_1-n_1=\frac{He}{K}(b-m_1),$$
$$n_1-m_2=b-m_1,$$
$$m_2-n_2=\frac{He}{K}(b-m_1),$$
$$\cdot$$
$$m_j-n_j=\frac{He}{K}(b-m_1),$$
$$n_j-a=b-m_1$$

Adding these equations, we find

$$(b-a)=(b-m_1)j\left(1+\frac{He}{K}\right)+1$$

The expenditure of the source of heat necessary to maintain the surface of the body A at the temperature b is $HS(b-a)$, when this surface sends its rays to a fixed surface maintained at the temperature a The expenditure is

$HS(b-m_1)$ when we place between the surface of the body A, and the fixed surface maintained at temperature a, a number j of isolated laminæ, thus the quantity of heat which the source must furnish is very much less in the second hypotheses than in the first, and the ratio of the two quantities is $\dfrac{1}{j\left(1+\dfrac{He}{K}\right)+1}$.

If we suppose the thickness e of the laminæ to be infinitely small, the ratio is $\dfrac{1}{j+1}$ The expenditure of the source is then inversely as the number of laminæ which cover the surface of the solid

91 The examination of these results and of those which we obtained when the intervals between successive enclosures were occupied by atmospheric air explain clearly why the separation of surfaces and the intervention of air assist very much in retaining heat

Analysis furnishes in addition analogous consequences when we suppose the source to be external, and that the heat which emanates from it crosses successively different diathermanous envelopes and the air which they enclose This is what has happened when experimenters have exposed to the rays of the sun thermometers covered by several sheets of glass within which different layers of air have been enclosed

For similar reasons the temperature of the higher regions of the atmosphere is very much less than at the surface of the earth.

green houses, drying houses, sheep folds, work-shops, or in many civil establishments, such as hospitals, barracks, places of assembly

In these different applications we must attend to accessory circumstances which modify the results of analysis, such as the unequal thickness of different parts of the enclosure, the introduction of air, &c , but these details would draw us away from our chief object, which is the exact demonstration of general principles.

For the rest, we have considered only, in what has just been said, the permanent state of temperature in closed spaces We can in addition express analyt

place

way,

dimensions affect the progress and duration of the heating, but these researches require a different analysis, the principles of which will be explained in the following chapters

SECTION VII *On the Uniform Movement of Heat in Three Dimensions*

92 Up to this time we have considered the uniform movement of heat in one

to have unequal actual temperatures represented by the linear equation $v=A+ax+by+cz$, x, y, z, being the rectangular co-ordinates of a molecule

whose temperature is v Suppose further that any external causes whatever acting on the six faces of the prism maintain every one of the molecules situated on the surface, at its actual temperature expressed by the general equation

$$v = A + ax + by + cz \qquad (a),$$

we shall prove that the same causes which by hypothesis, keep the outer layers of the solid in their initial state are sufficient to preserve also the actual temperatures of every one of the inner molecules, so that their temperatures do not cease to be represented by the linear equation

The examination of this question is an element of the general theory, it will serve to determine the laws of the varied movement of heat in the interior of a solid of any form whatever, for every one of the prismatic molecules of which the body is composed is during an infinitely small time in a state similar to that which the linear equation (a) expresses We may then, by following the ordinary principles of the differential calculus, easily deduce from the notion of uniform movement the general equations of varied movement

93 In order to prove that when the extreme layers of the solid preserve their temperatures no change can happen in the interior of the mass, it is sufficient to compare with each other the quantities of heat which, during the same instant, cross two parallel planes

Let b be the perpendicular distance of these two planes which we first suppose parallel to the horizontal plane of x and y Let m and m' be two infinitely near molecules, one of which is above the first horizontal plane and the other below it let x, y, z be the co-ordinates of the first molecule, and x', y', z' those of the second In like manner let M and M' denote two infinitely near molecules, separated by the second horizontal plane and situated, relatively to that plane in the same manner as m and m' are relatively to the first plane, that is to say, the co-ordinates of M are x, y, $z+\beta$, and those of M' are x', y', $z'+\beta$ It *is evident that the distance mm' of the two molecules m and m' is equal to the* distance MM' of the two molecules M and M', further let v be the temperature of m, and v' that of m', also let V and V' be the temperatures of M and M', it is easy to see that the two differences $v-v'$ and $V-V'$ are equal, in fact, substituting first the co-ordinates of m and m' in the general equation

$$v = A + ax + by + cz,$$

we find $$v - v' = a(x-x') + b(y-y') + c(z-z'),$$

and then substituting the co-ordinates of M and M', we find also $V-V' = a(x-x') + b(y-y') + c(z-z')$ Now the quantity of heat which m sends to m' depends on the distance mm', which separates these molecules, and it is proportional to the difference $v-v'$ of their temperatures This quantity of heat transferred may be represented by

$$q(v-v')dt,$$

the value of the coefficient q depends in some manner on the distance mm', and on the nature of the substance of which the solid is formed, dt is the duration of the instant The quantity of heat transferred from M to M', or the action of M on M' is expressed likewise by $q(V-V')dt$, and the coefficient q is the same as in the expression $q(v-v')dt$, since the distance MM' is equal to mm' and the two actions are effected in the same solid furthermore $V-V'$ is equal to $v-v'$, hence *the two actions are equal*

If we choose two other points n and n', very near to each other, which transfer heat across the first horizontal plane, we shall find in the same manner that their action is equal to that of two homologous points N and N' which communicate heat across the second horizontal plane We conclude then that the whole quantity of heat which crosses the first plane is equal to that which crosses the second plane during the same instant We should derive the same result from the comparison of two planes parallel to the plane of x and z, or from the comparison of two other planes parallel to the plane of y and z Hence any part whatever of the solid enclosed between six planes at right angles, receives through each of its faces as much heat as it loses through the opposite face, hence no portion of the solid can change temperature

94 Thus, *across one of these planes, a quantity of heat flows which is the same at all instants, and which is also the same for all other parallel sections*

In order to determine the value of this constant flow we shall compare it with the quantity of heat which flows uniformly in the most simple case, which has been already discussed The case is that of an infinite solid enclosed between two infinite planes and maintained in a constant state We have seen that the temperatures of the different points of the mass are in this case represented by the equation $v=A+cz$, we proceed to prove that the uniform flow *of heat per unit area propagated in the vertical direction in the infinite* solid is equal to that which flows in the same direction per unit area across the prism enclosed by six planes at right angles This equality necessarily exists if the coefficient c in the equation $v=A+cz$, belonging to the first solid, is the same as the coefficient c in the more general equation $v=A+ax+by+cz$ which represents the state of the prism In fact, denoting by H a plane in this prism perpendicular to z, and by m and μ two molecules very near to each other, the first of which m is below the plane H, and the second above this plane, let v be the temperature of m whose co-ordinates are x, y, z, and w the temperature of μ whose co-ordinates are $x+\alpha$, $y+\beta$, $z+\gamma$ Take a third molecule μ' whose co ordinates are $x-\alpha$, $y-\beta$, $z+\gamma$, and whose temperature may be denoted by w' We see that μ and μ' are on the same horizontal plane, and that the vertical drawn from the middle point of the line $\mu\mu'$, which joins these two points, passes through the point m, so that the distances $m\mu$ and $m\mu'$ are equal The action of m on μ, or the quantity of heat which the first of these molecules sends to the other across the plane H, depends on the difference $v-w$ of their temperatures The action of m on μ' depends in the same manner on the difference $v-w'$ of the temperatures of these molecules, since the distance of m from μ is the same as that of m from μ' Thus, expressing by $q(v-w)$ the action of m on μ during the unit of time, we shall have $q(v-w')$ to express the action of m on μ', q being a common unknown factor, depending on the distance $m\mu$ and on the nature of the solid Hence the sum of the two actions exerted during unit of time is $q(v-w+v-w')$

If instead of x, y, and z, in the general equation

$$v=A+ax+by+cz,$$

we substitute the co-ordinates of m and then those of μ and μ', we shall find

$$v-w=-a\alpha-b\beta-c\gamma,$$

$$v-w=+a\alpha+b\beta-c\gamma$$

The sum of the two actions of m on μ and of m on μ' is therefore $-2qc\gamma$

Suppose then that the plane H belongs to the infinite solid whose temperature equation is $v=A+cz$, and that we denote also by m μ and μ' those molecules in this solid whose co-ordinates are x, y, z for the first, $x+\alpha$, $y+\beta$, $z+\gamma$ for the second, and $x-\alpha$, $y-\beta$, $z+\gamma$ for the third we shall have, as in the preceding case, $v-w+v-w'=-2c\gamma$ Thus the sum of the two actions of m on μ and of m on μ', is the same in the infinite solid as in the prism enclosed between the six planes at right angles

We should obtain a similar result, if we considered the action of another point n below the plane H on two others ν and ν', situated at the same height above the plane Hence, the sum of all the actions of this kind, which are exerted across the plane H, that is to say the whole quantity of heat which, during unit of time, passes to the upper side of this surface, by virtue of the action of very near molecules which it separates, is always the same in both solids

95 In the second of these two bodies that which is bounded by two infinite planes, and whose temperature equation is $v=A+cz$, we know that the quantity of heat which flows during unit of time across unit of area taken on any horizontal section whatever is $-cK$, c being the coefficient of z, and K the specific conductivity, hence, the quantity of heat which, in the prism enclosed between six planes at right angles crosses during unit of time, unit of area taken on any horizontal section whatever, is also $-cK$, when the linear equation which represents the temperatures of the prism is

$$v=A+ax+by+cz$$

In the same way it may be proved that the quantity of heat which, during unit of time, flows uniformly across unit of area taken on any section whatever perpendicular to x, is expressed by $-aK$, and that the whole quantity which, during unit of time, crosses unit of area taken on a section perpendicular to y, is expressed by $-bK$

The theorems which we have demonstrated in this and the two preceding articles, suppose the direct action of heat in the interior of the mass to be limited to an extremely small distance, but they would still be true, if the rays of heat sent out by each molecule could penetrate directly to a quite appreciable distance, but it would be necessary in this case, as we have remarked in Article 70 to suppose that the cause which maintains the temperatures of the faces of the solid affects a part extending within the mass to a finite depth.

SECTION VIII *Measure of the Movement of Heat at a Given Point of a Solid Mass*

96 *It still remains for us to determine one of the principal elements of the theory of heat which consists in defining and in measuring exactly the quantity of heat which passes through every point of a solid mass across a plane whose direction is given*

If heat is unequally distributed amongst the molecules of the same body, the temperatures at any point will vary every instant. Denoting by t the time which has elapsed, and by v the temperature attained after a time t by an infinitely small molecule whose co-ordinates are x, y, z, the variable state of the solid will be expressed by an equation similar to the following $v=F(x, y, z, t)$ Suppose the function F to be given, and that consequently we can determine

required to determine what is the quantity of heat which during the instant dt will pass across the circle ω from the part of the solid which is below the plane into the part above it

All points extremely near to the point m and under the plane exert their action during the infinitely small instant dt, on all those which are above the plane and extremely near to the point m, that is to say, each of the points situated on one side of this plane will send heat to each of those which are situated on the other side

We shall consider as positive an action whose effect is to transport a certain quantity of heat above the plane, and as negative that which causes heat to pass below the plane The sum of all the partial actions which are exerted across the circle ω, that is to say, the sum of all the quantities of heat which, crossing any point whatever of this circle, pass from the part of the solid below the plane to the part above, compose the flow whose expression is to be found

It is easy to imagine that this flow may not be the same throughout the whole extent of the solid, and that if at another point m' we traced a horizontal circle ω' equal to the former, the two quantities of heat which rise above these planes ω and ω' during the same instant might not be equal these quantities are comparable with each other and their ratios are numbers which may be easily determined

97 We know already the value of the constant flow for the case of linear and uniform movement, thus in the solid enclosed between two infinite horizontal planes, one of which is maintained at the temperature a and the other at the temperature b, the flow of heat is the same for every part of the mass, we may regard it as taking place in the vertical direction only The value corresponding to unit of surface and to unit of time is $K\left(\frac{a-b}{e}\right)$ e denoting the perpendicular distance of the two planes, and K the specific conducibility the temperatures at the different points of the solid are expressed by the equation $v=a-\left(\frac{a-b}{e}\right)z$

When the problem is that of a solid comprised between six rectangular planes, pairs of which are parallel, and the temperatures at the different points are expressed by the equation

$$v=A+ax+by+cz,$$

the propagation takes place at the same time along the directions of x, of y, of z, the quantity of heat which flows across a definite portion of a plane parallel to that of x and y is the same throughout the whole extent of the prism, its value corresponding to unit of surface, and to unit of time is $-cK$, in the direction of z, it is $-bK$, in the direction of y, and $-aK$ in that of x

In general the value of the vertical flow in the two cases which we have just cited, depends only on the coefficient of z and on the specific conductivity K, this value is always equal to $-K\frac{dv}{dz}$

The expression of the quantity of heat which, during the instant dt, flows across a horizontal circle infinitely small, whose area is ω, and passes in this

manner from the part of the solid which is below the plane of the circle to the part above, is, for the two cases in question, $-K\frac{dv}{dz}\omega dt$

98 It is easy now to generalise this result and to recognise that it exists in every case of the varied movement of heat expressed by the equation $v=F(x, y\ z\ t)$

Let us in fact denote by x', y', z', the co-ordinates of this point m, and its actual temperature by v' Let $x'+\xi$, $y'+\eta$, $z'+\zeta$, be the co-ordinates of a point μ infinitely near to the point m, and whose temperature is w, ξ, η, ζ are quantities infinitely small added to the co-ordinates x', y', z', they determine the position of molecules infinitely near to the point m, with respect to three rectangular axes, whose origin is at m, parallel to the axes of x, y, and z Differentiating the equation

$$v=F(x, y, z, t)$$

and replacing the differentials by ξ, η, ζ, we shall have, to express the value of w which is equivalent to $v+dv$, the linear equation $w=v'+\frac{dv'}{dx}\xi+\frac{dv'}{dy}\eta+\frac{dv'}{dz}\zeta$, the coefficients v', $\frac{dv'}{dx}$, $\frac{dv'}{dy}$, $\frac{dv'}{dz}$, are functions of x, y, z, t, in which the given and constant values x', y', z', which belong to the point m, have been substituted for x, y, z

Suppose that the same point m belongs also to a solid enclosed between six rectangular planes and that the actual temperatures of the points of this prism whose dimensions are finite are expressed by the linear equation $w=A+a\xi+b\eta+c\zeta$ and that the molecules situated on the faces which bound the solid are maintained by some external cause at the temperature which is assigned to them by the linear equation ξ η, ζ are the rectangular co-ordinates of a molecule of the prism, whose temperature is w, referred to three axes whose origin is at m

This arranged, if we take as the values of the constant coefficients A, a, b, c, which enter into the equation for the prism, the quantities v', $\frac{dv'}{dx}$, $\frac{dv'}{dy}$, $\frac{dv'}{dz}$, which belong to the differential equation, the state of the prism expressed by the equation

$$w=v'+\frac{dv'}{dx}\xi+\frac{dv'}{dy}\eta+\frac{dv'}{dz}\zeta$$

will coincide as nearly as possible with the state of the solid, that is to say, all the molecules infinitely near to the point m will have the same temperature, whether we consider them to be in the solid or in the prism This coincidence of the solid and the prism is quite analogous to that of curved surfaces with the planes which touch them

It is evident from this, that the quantity of heat which flows in the solid across the circle ω during the instant dt, is the same as that which flows in the prism across the same circle for all the molecules whose actions concur in one effect or the other, have the same temperature in the two solids Hence, the flow in question, in one solid or the other, is expressed by $-K\frac{dv}{dz}\omega dt$ It would be $-K\frac{dv}{dy}\omega dt$, if the circle ω, whose centre is m, were perpendicular to the axis of y, and $-K\frac{dv}{dx}\omega dt$, if this circle were perpendicular to the axis of x

The value of the flow which we have just determined varies in the solid from one point to another, and it varies also with the time We might imagine it to have, at all the points of a unit of surface, the same value as at the point m, and to preserve this value during unit of time, the flow would then be expressed by $-K\frac{dv}{dz}$, it would be $-K\frac{dv}{dy}$ in the direction of y, and $-K\frac{dv}{dx}$ in that of x We shall ordinarily employ in calculation this value of the flow thus referred to unit of time and to unit of surface

[illegible]

given point m, a perpendicular must be raised upon the plane, and at every point of this perpendicular ordinates must be drawn to represent the actual

a parallel to the abscissæ

The result which we have just explained is that of which the most frequent applications have been made in the theory of heat We cannot discuss the different problems without forming a very exact idea of the value of the flow at every point of a body whose temperatures are variable It is necessary to insist on this fundamental notion, an example which we are about to refer to will

Now, we shall prove in the sequel, that the variable state of this solid is expressed by the equation

$$v = e^{-gt} \cos x \cos y \cos z,$$

the coefficient g is equal to $\frac{3K}{C\,D}$, K is the specific conductivity of the substance of which the solid is formed, D is the density and C the specific heat, t is the time elapsed

the value of the flow, at this point and across the plane, is $-K\frac{dv}{dz}$, or $Ke^{-gt}\cos x \cos y \sin z$ The quantity of heat which, during the instant dt, crosses an

infinitely small rectangle, situated on this plane, and whose sides are dx and dy, is

$$K e^{-gt} \cos x \cos y \sin z \, dx \, dy \, dt$$

Thus the whole heat which, during the instant dt, crosses the entire area of the same plane, is

$$K e^{-gt} \sin z \, dt \iint \cos x \cos y \, dx \, dy,$$

the double integral being taken from $x = -\frac{1}{2}\pi$ up to $x = \frac{1}{2}\pi$, and from $y = -\frac{1}{2}\pi$ up to $y = \frac{1}{2}\pi$ We find then for the expression of this total heat,

$$4 \, K e^{-gt} \sin z \, dt$$

If then we take the integral with respect to t, from $t = 0$ to $t = t$, we shall find the quantity of heat which has crossed the same plane since the cooling began up to the actual moment This integral is $\frac{4K}{g} \sin z (1 - e^{-gt})$, its value at the surface is

$$\frac{4K}{g} (1 - e^{-gt}),$$

so that after an infinite time the quantity of heat lost through one of the faces is $\frac{4K}{g}$ The same reasoning being applicable to each of the six faces, we conclude that the solid has lost by its complete cooling a total quantity of heat equal to $\frac{24K}{g}$ or $8CD$, since g is equivalent to $\frac{3K}{CD}$ The total heat which is dissipated during the cooling must indeed be independent of the special conductivity K, which can only influence more or less the velocity of cooling

100 A We may determine in another manner the quantity of heat which the solid loses during a given time, and this will serve in some degree to verify the preceding calculation In fact, the mass of the rectangular molecule whose [illegible]

temperature v, the expenditure of heat would be $v \, CD \, dx \, dy \, dz$

It follows from this, that in order [illegible] the heat of the solid, after time t, exceeds that [illegible]

we must take the multiple integral [illegible]

$x = -\frac{1}{2}\pi$, $x = \frac{1}{2}\pi$, $y = -\frac{1}{2}\pi$, $y = \frac{1}{2}\pi$, $z = -\frac{1}{2}\pi$, $z = \frac{1}{2}\pi$

We thus find, on substituting for v its value, that is to say

$$e^{-gt} \cos x \cos y \cos z,$$

[illegible] that which belongs to the temperature 0 is [illegible]

general equations of the propagation of heat, which is the subject of the next chapter.

SECOND CHAPTER

Equations of the Movement of Heat

SECTION I *Equation of the Varied Movement of Heat in a Ring*

101

may easily be avoided There are several problems which it is preferable to treat in a special manner by expressing the conditions which are appropriate to them, we proceed to adopt this course and examine separately the problems which have been enunciated in the first section of the introduction, we will limit ourselves at first to forming the differential equations, and shall give the integrals of them in the following chapters

102 We have already considered the uniform movement of heat in a prismatic bar of small thickness whose extremity is immersed in a constant source of heat This first case offered no difficulties since there was no reference except to the permanent state of the temperatures, and the equation which

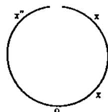


Fig 3

measures the external conductivity, K the internal conductivity, C the specific capacity for heat, D the density The line $oxx'x''$ represents the mean circumference of the armlet, or that line which passes through the centres of figure of all the sections, the distance of a section from the origin o is measured by the arc whose length is x, R is the radius of the mean circumference

It is supposed that on account of the small dimensions and of the form of the section, we may consider the temperature at the different points of the same section to be equal

103 Imagine that initial arbitrary temperatures have been given to the

ring, and dispersed at the surface it is required to determine what will be the state of the solid at any given instant

discovered

104 We will consider the movement of heat in an infinitely small slice, enclosed between a section made at distance x and another section made at distance $x+dx$ The state of this slice for the duration of one instant is that of an infinite solid terminated by two parallel planes maintained at unequal temperatures thus the quantity of heat which flows during this instant dt across the first section, and passes in this way from the part of the solid which precedes the slice into the slice itself, is measured according to the principles established in the introduction, by the product of four factors, that is to say, the conducibility K, the area of the section S, the ratio $-\frac{dv}{dx}$, and the duration of the instant, its expression is $-KS\frac{dv}{dx}dt$ To determine the quantity of heat which escapes from the same slice across the second section, and passes into the contiguous part of the solid, it is only necessary to change x into $x+dx$ in the preceding expression, or, which is the same thing, to add to this expression its differential taken with respect to x, thus the slice receives through one of its faces a quantity of heat equal to $-KS\frac{dv}{dx}dt$, and loses through the opposite face a quantity of heat expressed by

$$-KS\frac{dv}{dx}dt-KS\frac{d^2v}{dx^2}dx\,dt$$

It acquires therefore by reason of its position a quantity of heat equal to the difference of the two preceding quantities, that is

$$KS\frac{d^2v}{dx^2}dx\,dt$$

On the other hand, the same slice, whose external surface is $l dx$ and whose temperature differs infinitely little from v, allows a quantity of heat equivalent to $hlv\,dx\,dt$ to escape into the air during the instant dt, it follows from this that this infinitely small part of the solid retains in reality a quantity of heat represented by $KS\frac{d^2v}{dx^2}dx\,dt-hlv\,dx\,dt$ which makes its temperature vary The amount of this change must be examined

105 The coefficient C expresses how much heat is required to raise unit of

re 1,

the

, we

shall have $CDS\,dx$ as the quantity of heat which would raise the volume of the slice from temperature 0 up to temperature 1 Hence the increase of temperature which results from the addition of a quantity of heat equal to $KS\frac{d^2v}{dx^2}dx\,dt$ $-hlv\,dx\,dt$ will be found by dividing the last quantity by $CDS\,dx$ Denoting therefore, according to custom, the increase of temperature which takes place during the instant dt by $\frac{dv}{dt}dt$, we shall have the equation

$$\frac{dv}{dt}=\frac{K}{CD}\frac{d^2v}{dx^2}-\frac{hl}{CDS}v \qquad (b)$$

We shall explain in the sequel the use which may be made of this equation to determine the complete solution, and what the difficulty of the problem

consists in, we limit ourselves here to a remark concerning the permanent state of the armlet

106 Suppose that, the plane of the ring being horizontal, sources of heat, each of which exerts a constant action, are placed below different points m, n, p, q etc , heat will be propagated in the solid, and that which is dissipated through the surface being incessantly replaced by that which emanates from the sources, the temperature of every section of the solid will approach more and more to a stationary value which varies from one section to another In order to express by means of equation (b) the law of the latter temperatures, which would exist of themselves if they were once established we must suppose that the quantity v does not vary with respect to t, which annuls the term $\frac{dv}{dt}$ We thus have the equation

$$\frac{d^2v}{dx^2} = \frac{hl}{KS}v, \text{ whence } v = Me^{-x\sqrt{\frac{hl}{KS}}} + Ne^{+x\sqrt{\frac{hl}{KS}}},$$

M and N being two constants

107 Suppose a portion of the circumference of the ring, situated between two successive sources of heat, to be divided into equal parts, and denote by v_1, v_2, v_3, v_4, &c , the temperatures at the points of division whose distances from the origin are x_1, x_2, x_3, x_4, &c , the relation between v and x will be given by the preceding equation, after the two constants have been determined by means of the two values of v corresponding to the sources of heat Denoting by α the quantity $e^{-\sqrt{\frac{hl}{KS}}}$, and by λ the distance $x_2 - x_1$ of two consecutive points of division, we shall have the equations

$$v_1 = M\alpha^{x_1} + N\alpha^{-x_1},$$
$$v_2 = M\alpha^{\lambda}\ \alpha^{x_1} + N\alpha^{-\lambda}\alpha^{-x_1},$$
$$v_3 = M\alpha^{2\lambda}\alpha^{x_1} + N\alpha^{-2\lambda}\alpha^{-x_1},$$

whence we derive the following relation $\frac{v_1 + v_3}{v_2} = \alpha^{\lambda} + \alpha^{-\lambda}$

We should find a similar result for the three points whose temperatures are v_2, v_3, v_4, and in general for any three consecutive points It follows from this that if we observed the temperatures t_1, v_2, v_3, v_4, t_5 &c of several successive points, all situated between the same two sources m and n and separated by a constant interval λ, we should perceive that any three consecutive temperatures are always such that the sum of the two extremes divided by the mean gives a constant quotient $\alpha^{\lambda} + \alpha^{-\lambda}$

108 If, in the space included between the next two sources of heat n and p, the temperatures of other different points separated by the same interval λ were observed, it would still be found that for any three consecutive points, the sum of the two extreme temperatures, divided by the mean gives the same quotient $\alpha^{\lambda} + \alpha^{-\lambda}$ The value of this quotient depends neither on the position nor on the intensity of the sources of heat

109 Let q be this constant value, we have the equation

$$v_3 = qv_2 - v_1,$$

we see by this that when the circumference is divided into equal parts, the temperatures at the points of division, included between two consecutive sources of heat, are represented by the terms of a recurr
of relation is composed of two terms q and -1

Experiments have fully confirmed this result We have exposed a metallic ring to the permanent and simultaneous action of different sources of heat and we have observed the *stationary temperatures of several points separated* by constant intervals, we always found that the temperatures of any three consecutive points, not separated by a source of heat, were connected by the relation in question Even if the sources of heat be multiplied, and in whatever manner they be disposed, no change can be effected in the numerical value of the quotient $\frac{v_1+v_3}{v_2}$, it depends only on the dimensions or on the nature of the ring and not on the manner in which that solid is heated

110 *When we have found, by observation, the value of the constant quotient* q or $\frac{v_1+v_3}{v_2}$, the value of α^λ may be derived from it by means of the equation $\alpha^\lambda+\alpha^{-\lambda}=q$ One of the roots is α^λ, and other root is $\alpha^{-\lambda}$ This quantity being determined, we may derive from it the value of the ratio $\frac{h}{K}$, which is $\frac{S}{l}(\log\alpha)^2$ Denoting α^λ by ω, *we shall have* $\omega^2-q\omega+1=0$ *Thus the ratio of the* two conductivities is found by multiplying $\frac{S}{l}$ by the square of the hyperbolic logarithm of one of the roots of the equation $\omega^2-q\omega+1=0$, and dividing the product by λ^2

SECTION II *Equation of the Varied Movement of Heat in a Solid Sphere*

111 A solid homogeneous mass of the form of a sphere having been immersed for an infinite time in a medium maintained at a permanent temperature 1, is then exposed to air which is kept at temperature 0 and displaced with *constant velocity it is required to determine the successive states of the* body during the whole time of the cooling

Denote by x the distance of any point whatever from the centre of the sphere and by v the temperature of the same point after a time t has elapsed and suppose, to make the problem more general, that the initial temperature common to all points situated at the distance x from the centre, *is different for* different values of x which is what would have been the case if the immersion had not lasted for an infinite time

Points of the solid, equally distant from the centre, will not cease to have a common temperature, v is thus a function of x and t When we suppose $t=0$, it is essential that the value of this function should agree with the *initial state* which is given, and which is entirely arbitrary

112 We shall consider the instantaneous movement of heat in an infinitely thin shell, bounded by two spherical surfaces whose radii are x and $x+dx$. the quantity of heat which, during an infinitely small instant dt, crosses the lesser surface whose radius is x, and so passes from that part of the solid which is nearest to the centre into the spherical shell, is equal to the product of four factors which are the conductivity K, the duration dt, the extent $4\pi x^2$ of surface, and the ratio $\frac{dv}{dx}$, taken with the negative sign, it is expressed by

$$-4K\pi x^2\frac{dv}{dx}dt$$

To determine the quantity of heat which flows during the same instant through the second surface of the same shell and passes from this shell into the part of the solid which envelops it, x must be changed into $x+dx$, in the preceding expression that is to say, to the term $-4K\pi x^2 \frac{dv}{dx} dt$ must be added the differential of this term taken with respect to x We thus find

$$-4K\pi x^2 \frac{dv}{dx} dt - 4K\pi d\left(x^2 \frac{dv}{dx}\right) dt$$

as the expression of the quantity of heat which leaves the spherical shell across its second surface, and if we subtract this quantity from that which enters through the first surface, we shall have $4K\pi d\left(x^2\frac{dv}{dx}\right) dt$ This difference is evidently the quantity of heat which accumulates in the intervening shell, and whose effect is to vary its temperature

113 The coefficient C denotes the quantity of heat which is necessary to raise, from temperature 0 to temperature 1, a definite unit of weight, D is the weight of unit of volume, $4\pi x^2 dx$ is the volume of the intervening layer, differing from it only by a quantity which may be omitted hence $4\pi CDx^2dx$ is the quantity of heat necessary to raise the intervening shell from temperature 0 to temperature 1 Hence it is requisite to divide the quantity of heat which accumulates in this shell by $4\pi CDx^2dx$, and we shall then find the increase of its temperature v during the time dt We thus obtain the equation

$$dv = \frac{K}{CD} dt \frac{d\left(x^2 \frac{dv}{dx}\right)}{x^2 dx}$$

or

$$\frac{dv}{dt} = \frac{K}{CD} \left(\frac{d^2v}{dx^2} + \frac{2}{x} \frac{dv}{dx}\right) \qquad (c)$$

[illegible] the law of the movement of heat in

case we may imagine the sphere, whose variable state it is desired to determine, to be covered by a very thin envelope on which the cooling agency exerts [illegible] alone adheres to

the temperature from ever being above or below zero To express this condition theoretically, the function v, which contains x and t must be made to become nul, when we give to x its complete value X equal to the radius of the sphere, whatever else the value of t may be We should then hav

hypothesis if we denote by $\phi(x, t)$ the function of x and t, which expresses the value of v, the two equations

$$\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2 v}{dx^2} + \frac{2}{x}\frac{dv}{dx}\right), \quad \text{and} \quad \phi(X, t) = 0$$

Further it is necessary that the initial state should be represented by the same function $\phi(x, t)$ we shall therefore have as a second condition $\phi(x\ 0) = 1$ Thus the variable state of a solid sphere on the hypothesis which we have first described will be represented by a function v which must satisfy the three preceding equations The first is general and belongs at every instant to all points of the mass, the second affects only the molecules at the surface and the third belongs only to the initial state

115 If the solid is being cooled in air the second equation is different it must then be imagined that the very thin envelope is maintained by some external cause in a state such as to produce the escape from the sphere at every instant of a quantity of heat equal to that which the presence of the medium can carry away from it

Now the quantity of heat which, during an infinitely small instant dt flows within the interior of the solid across the spherical surface situate at distance x, is equal to $-4K\pi x^2 \frac{dv}{dx} dt$, and this general expression is applicable to all values of x Thus by supposing $x = X$ we shall ascertain the quantity of heat which in the variable state of the sphere would pass across the very thin envelope which bounds it on the other hand the external surface of the solid having a variable temperature which we shall denote by V would permit the escape into the air of a quantity of heat proportional to that temperature and to the extent of the surface, which is $4\pi X^2$ The value of this quantity is $4h\pi X^2 V dt$

To express as is supposed that the action of the envelope supplies the place, at every instant, of that which would result from the presence of the medium it is sufficient to equate the quantity $4h\pi X^2 V dt$ to the value which the expression $-4K\pi X^2 \frac{dv}{dx} dt$ receives when we give to x its complete value X hence we obtain the equation $\frac{dv}{dx} = -\frac{h}{K} v$, which must hold when in the functions $\frac{dv}{dx}$ and v we put instead of x its value X, which we shall denote by writing it in the form $K\frac{dV}{dx} + hV = 0$

116 The value of $\frac{dv}{dx}$ taken when $x = X$, must therefore have a constant ratio $-\frac{h}{K}$ to the value of v which corresponds to the same point Thus we shall suppose that the external cause of the cooling determines always the state of the very thin envelope, in such a manner that the value of $\frac{dv}{dx}$ which results from this state is proportional to the value of v corresponding to $x = X$, and that the constant ratio of these two quantities is $-\frac{h}{K}$ This condition being fulfilled by means of some cause always present, which prevents the extreme

value of $\frac{dv}{dx}$ from being anything else but $-\frac{h}{K}v$, the action of the envelope will take the place of that of the air

It is not necessary to suppose the envelope to be extremely thin, and it will be seen in the sequel that it may have an indefinite thickness Here the thickness is considered to be indefinitely small, so as to fix the attention on the state of the surface only of the solid

117 Hence it follows that the three equations which are required to determine the function $\phi(x, t)$ or v are the following,

$$\frac{dt}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2} + \frac{2}{x}\frac{dv}{dx}\right), \quad K\frac{dV}{dx}+hV=0, \quad \phi(x, 0)=1$$

The first applies to all possible values of x and t, the second is satisfied when $x=X$, whatever be the value of t, and the third is satisfied when $t=0$, whatever be the value of x

which is more general than the foregoing the given function, which expresses the initial temperature of the molecules situated at distance x from the centre of the sphere, will be represented by $F(x)$, the third equation will then be replaced by the following $\phi(x, 0)=F(x)$

Nothing more remains than a purely analytical problem, whose solution will be given in one of the following chapters It consists in finding the value of v, by means of the general condition, and the two special conditions to which it is subject

SECTION III *Equations of the Varied Movement of Heat in a Solid Cylinder*

118 A solid cylinder of infinite length, whose side is perpendicular to its

to a current of colder air, it is required to determine the temperatures of the different layers, after a given time

x denotes the radius of a cylindrical surface, all of whose points are equally distant from the axis X is the radius of the cylinder, v is the temperature

radius is $x+dx$ The quantity of heat which this portion receives during the instant dt, from the part of the solid which it envelops, that is to say, the quantity which during the same time crosses the cylindrical surface whose radius is x, and whose length is supposed to be equal to unity, is expressed by

$$-2K\pi x\frac{dv}{dx}dt$$

To find the quantity of heat which, crossing the second surface whose radius is $x+dx$, passes from the infinitely thin shell into the part of the solid which envelops it, we must, in the foregoing expression, change x into $x+dx$, or, which is the same thing, add to the term

$$-2K\pi x \frac{dv}{dx}\, dt,$$

the differential of this term, taken with respect to x Hence the difference of the heat received and the heat lost, or the quantity of heat which accumulating in the infinitely thin shell determines the changes of temperature, is the same differential taken with the opposite sign, or

$$2K\pi \; dt \cdot d\left(x \frac{dv}{dx}\right),$$

on the other hand, the volume of this intervening shell is $2\pi x dx$, and $2CD\pi x dx$ expresses the quantity of heat required to raise it from the temperature 0 to the temperature 1, C being the specific heat, and D the density Hence the quotient

$$\frac{2K\pi \; dt \; d\left(x \dfrac{dv}{dx}\right)}{2CD\pi x dx}$$

is the increment which the temperature receives during the instant dt Whence we obtain the equation

$$\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2} + \frac{1}{x}\,\frac{dv}{dx}\right)$$

120 The quantity of heat which, during the instant dt, crosses the cylindrical surface whose radius is x, being expressed in general by $2K\pi x \dfrac{dv}{dx}\, dt$, we shall find that quantity which escapes during the same time from the surface of the solid, by making $x = X$ in the foregoing value, on the other hand, the same quantity, dispersed into the air, is, by the principle of the communication of heat, equal to $2\pi X h v dt$, we must therefore have at the surface the definite equation $-K\dfrac{dv}{dx} = hv$ The nature of these equations is explained at greater length, either in the articles which refer to the sphere, or in those wherein the general equations have been given for a body of any form whatever The function v which represents the movement of heat in an infinite cylinder must therefore satisfy, 1st, the general equation $\dfrac{dv}{dt} = \dfrac{K}{CD}\left(\dfrac{d^2v}{dx^2} + \dfrac{1}{x}\,\dfrac{dv}{dx}\right)$, which applies whatever x and t may be, 2nd, the definite equation $\dfrac{h}{K}v + \dfrac{dv}{dx} = 0$, which is true, whatever the variable t may be, when $x = X$, 3rd, the definite equation $v = F(x)$ The last condition must be satisfied by all values of v, when t is made equal to 0, whatever the variable x may be The arbitrary function $F(x)$ is supposed to be known, it corresponds to the initial state.

SECTION IV *Equations of the Uniform Movement of Heat in a Solid Prism of Infinite Length*

121 A prismatic bar is immersed at one extremity in a constant source of heat which maintains that extremity at the temperature A, the rest of the bar, whose length is infinite, continues to be exposed to a uniform current of atmospheric air maintained at temperature 0, it is required to determine the highest temperature which a given point of the bar can acquire

The problem differs from that of Article 73, since we now take into consideration all the dimensions of the solid, which is necessary in order to obtain an exact solution

We are led, indeed, to suppose that in a bar of very small thickness all points of the same section would acquire sensibly equal temperatures, but some uncertainty may rest on the results of this hypothesis It is therefore preferable to solve the problem rigorously, and then to examine, by analysis, up to what point, and in what cases, we are justified in considering the temperatures of different points of the same section to be equal

[illegible] bar, is a square [illegible] origin is at the [illegible] the bar are x, y, z, and v denotes the fixed temperature at the same point

The problem consists in determining the temperatures which must be assigned to different points of the bar, in order that they may continue to exist without any change, so long as the extreme surface A, which communicates with the source of heat, remains subject, at all its points, to the permanent temperature A, thus v is a function of x, y, and z

123 Consider the movement of heat in a prismatic molecule, enclosed between six planes perpendicular to the three axes of x, y, and z The first three planes pass through the point m whose co-ordinates are x, y, z, and the [illegible] $y+dy$, $z+dz$ [illegible] me across [illegible] we must remember that the extent of the surface of the molecule on this plane is $dy\,dz$, and that the flow across this area is, according to the theorem of Article 98, equal to $-K\frac{dv}{dx}$; thus the molecule receives across the rectangle $dy\,dz$ passing through the point m a quantity of heat expressed by $-K\,dy\,dz\frac{dv}{dx}$ To find the quantity of heat which crosses the opposite face, and escapes from the molecule, we must substitute, in the preceding expression, $x+dx$ for x, or, which is the same thing, add to this expression its differential taken with respect to x only, whence we conclude that the molecule loses, at its second face perpendicular to x, a quantity of heat equal to

$$-Kdydz\frac{dv}{dx}\;-Kdydzd\left(\frac{dv}{dx}\right),$$

we must therefore subtract this from that which enters at the opposite face; the differences of these two quantities is

$$K\,dy\,dz\,d\left(\frac{dv}{dx}\right),\text{ or, } K\,dz\,dy\,dz\frac{d^2v}{dx^2};$$

thus expresses the quantity of heat accumulated in the molecule in consequence of the propagation in direction of x, which accumulated heat would make the temperature of the molecule vary, if it were not balanced by that which is lost in some other direction

It is found in the same manner that a quantity of heat equal to $-K\,dz\,dx\frac{dv}{dy}$ enters the molecule across the plane passing through the point m perpendicular to y, and that the quantity which escapes at the opposite face is

$$-K\,dz\,dx\frac{dv}{dy}-K\,dz\,dx\,d\left(\frac{dv}{dy}\right),$$

the last differential being taken with respect to y only Hence the difference of the two quantities, or $K dx dy dz\frac{d^2v}{dy^2}$, expresses the quantity of heat which the molecule acquires, in consequence of the propagation in direction of y

Lastly, it is proved in the same manner that the molecule acquires, in consequence of the propagation in direction of z, a quantity of heat equal to $K\,dx\,dy\,dz\frac{d^2v}{dz^2}$ Now, in order that there may be no change of temperature, it is necessary for the molecule to retain as much heat as it contained at first, so that the heat it acquires in one direction must balance that which it loses in another Hence the sum of the three quantities of heat acquired must be nothing, thus we form the equation

$$\frac{d^2v}{dx^2}+\frac{d^2v}{dy^2}+\frac{d^2v}{dz^2}=0$$

124 It remains now to express the conditions relative to the surface If we suppose the point m to belong to one of the faces of the prismatic bar, and the face to be perpendicular to z, we see that the rectangle $dxdy$, during unit of time, permits a quantity of heat equal to $V\,h\,dx\,dy$ to escape into the air, V denoting the temperature of the point m of the surface, namely what $\phi\,(x\ y, z)$ the function sought becomes when z is made equal to l, half the dimension of the prism On the other hand, the quantity of heat which, by virtue of the action of the molecules, during unit of time, traverses an infinitely small surface ω, situated within the prism, perpendicular to z, is equal to $-K\omega\frac{dv}{dz}$, according to the theorems quoted above This expression is general, and applying it to points for which the co-ordinate z has its complete value l, we conclude from it that the quantity of heat which traverses the rectangle $dx\,dy$ taken at the surface is $-K\,dx\,dy\frac{dv}{dz}$, giving to z in the function $\frac{dv}{dz}$ its complete value l Hence the two quantities $-K\,dx\,dy\frac{dv}{dz}$, and $h\,dx\,dy\,v$, must be equal, in order that the action of the molecules may agree with that of the medium This equality must also exist when we give to z in the functions $\frac{dv}{dz}$ and v the value $-l$, which it has at the face opposite to that first considered Further, the quantity of heat which crosses an infinitely small surface ω, perpendicular to the axis of y, being $-K\omega\frac{dv}{dy}$, it follows that that which flows across a

rectangle $dz\,dx$ taken on a face of the prism perpendicular to y is $-K\,dz\,dx\frac{dv}{dy}$ giving to y in the function $\frac{dv}{dy}$ its complete value l Now this rectangle $dz\,dx$ permits a quantity of heat expressed by $hv\,dx\,dz$ to escape into the air, the equation $hv=-K\frac{dv}{dy}$ becomes therefore necessary, when y is made equal to l or $-l$ in the functions v and $\frac{dv}{dy}$

125 The value of the function v must by hypothesis be equal to A, when we suppose $x=0$, whatever be the values of y and z Thus the required function v is determined by the following conditions 1st, *for all values of x, y z, it satisfies the general equation*

$$\frac{d^2v}{dx^2}+\frac{d^2v}{dy^2}+\frac{d^2v}{dz^2}=0,$$

2nd, it satisfies the equation $\frac{h}{K}v+\frac{dv}{dy}=0$, when y is equal to l or $-l$, whatever x and z may be or satisfies the equation $\frac{h}{K}v+\frac{dv}{dz}=0$ when z is equal to l or $-l$, whatever x and y may be, 3rd, it satisfies the equation $v=A$, when $x=0$ whatever y and z may be

SECTION V *Equations of the Varied Movement of Heat in a Solid Cube*

126 A solid in the form of a cube, all of whose points have acquired the same temperature, is placed in a uniform current of atmospheric air maintained at temperature 0 It is required to determine the successive states of the body during the whole time of the cooling

The centre of the cube is taken as the origin of rectangular coordinates, the

experience during the instant dt, by virtue of the action of the molecules which are extremely near to it We consider then a prismatic molecule enclosed between six planes at right angles, the first three pass through the point m, whose co-ordinates are x, y, z, and the three others, through the point m', whose co-ordinates are

$$x+dx,\ y+dy,\ z+dz$$

The quantity of heat which during the instant dt passes into the molecule across the first rectangle $dy\,dz$ perpendicular to x, is $-K\,dy\,dz\frac{dv}{dx}dt$, and that which escapes in the same time from the molecule, through the opposite face, is found by writing $x+dx$ in place of x in the preceding expression, it is

$$-K\,dy\,dz\left(\frac{dv}{dx}\right)dt-K\,dy\,dz\,d\left(\frac{dv}{dx}\right)dt,$$

the differential being taken with respect to x only The quantity of heat which during the instant dt enters the molecule, across the first rectangle $dz\,dx$ perpendicular to the axis of y, is $-K\,dz\,dx\frac{dv}{dy}dt$, and that which escapes from the molecule during the same instant, by the opposite face, is

$$-K\,dz\,dx\frac{dv}{dy}dt - K\,dz\,dx\,d\left(\frac{dv}{dy}\right)dt,$$

the differential being taken with respect to y only The quantity of heat which the molecule receives during the instant dt, through its lower face perpendicular to the axis of z, is $-K\,dx\,dy\frac{dv}{dz}dt$, and that which it loses through the opposite face is

$$-K\,dx\,dy\frac{dv}{dz}dt - K\,dx\,dy\,d\left(\frac{dv}{dz}\right)dt,$$

the differential being taken with respect to z only

The sum of all the quantities of heat which escape from the molecule must now be deducted from the sum of the quantities which it receives, and the difference is that which determines its increase of temperature during the instant this difference is

$$K\,dy\,dz\,d\left(\frac{dv}{dx}\right)dt + K\,dz\,dx\,d\left(\frac{dv}{dy}\right)dt + K\,dx\,dy\,d\left(\frac{dv}{dz}\right)dt,$$

$$\text{or } K\,dx\,dy\,dz\left\{\frac{d^2v}{dx^2}+\frac{d^2v}{dy^2}+\frac{d^2v}{dz^2}\right\}dt$$

128 If the quantity which has just been found be divided by that which is necessary to raise the molecule from the temperature 0 to the temperature 1, the increase of temperature which is effected during the instant dt will become known Now the latter quantity is $CD\,dx\,dy\,dz$ for C denotes the capacity of the substance for heat D its density, and $dx\,dy\,dz$ the volume of the molecule The movement of heat in the interior of the solid is therefore expressed by the equation

$$\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2}+\frac{d^2v}{dy^2}+\frac{d^2v}{dz^2}\right) \qquad (d)$$

129 It remains to form the equations which relate to the state of the surface, which presents no difficulty, in accordance with the principles which we have established In fact, the quantity of heat which during the instant dt crosses the rectangle $dz\,dy$ traced on a plane perpendicular to x, is $-K\,dy\,dz\frac{dv}{dx}dt$ This result which applies to all points of the solid ought to hold when the

ought therefore to have, when $x=l$, the equation $hv=-K\frac{dv}{dx}$ This condition must also be satisfied when $x=-l$

It will be found also that, the quantity of heat which crosses the rectangle

$dz\,dx$ situated on a plane perpendicular to the axis of y being in general $-K\,dz\,dx\frac{dv}{dy}$, and that which escapes at the surface into the air across the same rectangle being $hv\,dz\,dx\,dt$, we must have the equation $hv+K\frac{dv}{dy}=0$, when $y=l$ or $-l$ Lastly, we obtain in like manner the definite equation

$$hv+K\frac{dv}{dz}=0,$$

which is satisfied when $z=l$ or $-l$

130 The function sought, which expresses the varied movement of heat in the interior of a solid of cubic form, must therefore be determined by the following conditions

1st It satisfies the general equation

$$\frac{dv}{dt}=\frac{K}{C\,D}\left(\frac{d^2v}{dx^2}+\frac{d^2v}{dy^2}+\frac{d^2v}{dz^2}\right),$$

2nd It satisfies the three definite equations

$$hv+K\frac{dv}{dx}=0,\quad hv+K\frac{dv}{dy}=0,\quad hv+K\frac{dv}{dz}=0,$$

which hold when $x=\pm l$, $y=\pm l$, $z=\pm l$,

3rd If in the function v which contains x, y z, t we make $t=0$ whatever be the values of x, y, and z, we ought to have, according to hypothesis, $v=A$, which is the initial and common value of the temperature

131 The equation arrived at in the preceding problem represents the movement of heat in the interior of all solids Whatever, in fact the form of the body may be, it is evident that, by decomposing it into prismatic molecules, we shall obtain this result We may therefore limit ourselves to demonstrating in this manner the equation of the propagation of heat But in order to make the exhibition of principles more complete, and that we may collect into a small number of consecutive articles the theorems which serve to establish the general equation of the propagation of heat in the interior of solids, and the equations which relate to the state of the surface we shall proceed in the two following sections, to the investigation of these equations independently of any particular problem, and without reverting to the elementary propositions which we have explained in the introduction

SECTION VI *General equation of the Propagation of Heat in the Interior of Solids*

132 THEOREM I *If the different points of a homogeneous solid mass, enclosed between six planes at right angles, have actual temperatures determined by the linear equation*

$$v=A-ax-by-cz, \qquad (a),$$

and if the molecules situated at the external surface on the six planes which bound the prism are maintained, by any case whatever, at the temperature expressed by the equation (a) all the molecules situated in the interior of the mass will of themselves retain their actual temperatures, so that there will be no change in the state of the prism

v denotes the actual temperature of the point whose co-ordinates are x, y, z, A, a, b, c, are constant coefficients

To prove this proposition, consider in the solid any three points whatever $mM\mu$, situated on the same straight line $m\mu$, which the point M divides into two equal parts, denote by x, y, z the co-ordinates of the point M, and its temperature by v, the co-ordinates of the point μ by $x+\alpha$, $y+\beta$, $z+\gamma$, and its temperature by w, the co ordinates of the point m by $x-\alpha$, $y-\beta$, $z-\gamma$, and its temperature by u, we shall have

$$v=A-ax-by-cz,$$
$$w=A-a(x+\alpha)-b(y+\beta)-c(z+\gamma),$$
$$u=A-a(x-\alpha)-b(y-\beta)-c(z-\gamma),$$

whence we conclude that,

$$v-w=a\alpha+b\beta+c\gamma, \text{ and } u-v=a\alpha+b\beta+c\gamma,$$

therefore $$v-w=u-v$$

Now the quantity of heat which one point receives from another depends on the distance between the two points and on the difference of their temperatures Hence the action of the point M on the point μ is equal to the action of m on M, thus the point M receives as much heat from m as it gives up to the point μ

We obtain the same result, whatever be the direction and magnitude of the line which passes through the point M, and is divided into two equal parts Hence it is impossible for this point to change its temperature, for it receives from all parts as much heat as it gives up

The same reasoning applies to all other points, hence no change can happen in the state of the solid

133 COROLLARY I A solid being enclosed between two infinite parallel planes A and B, if the actual temperature of its different points is supposed to be expressed by the equation $v=1-z$, and the two planes which bound it are maintained by any cause whatever, A at the temperature 1, and B at the temperature 0, this particular case will then be included in the preceding theorem, if we make $A=1$, $a=0$, $b=0$, $c=1$

134 COROLLARY II If in the interior of the same solid we imagine a plane M parallel to those which bound it, we see that a certain quantity of heat flows across this plane during unit of time, for two very near points, such as m and n, one of which is below the plane and the other above it, are unequally heated, the first, whose temperature is highest, must therefore send to the second, during each instant, a certain quantity of heat which, in some cases, may be very small and even insensible, according to the nature of the body and the distance of the two molecules

The same is true for any two other points whatever separated by the plane That which is most heated sends to the other a certain quantity of heat, and the sum of these partial actions or of all the quantities of heat sent across the plane, composes a continual flow whose value does not change, since all the molecules preserve their temperatures It is easy to prove *that this flow, or the quantity of heat which crosses the plane M during the unit of time, is equivalent*

the plane N If the quantity of heat, which in passing the plane M enters the part of the mass which is considered, were not equal to that which escapes by the opposite surface N, the solid enclosed between the two surfaces would acquire fresh heat, or would lose a part of that which it has, and its temperatures would not be constant, which is contrary to the preceding corollary

135 The measure of the specific conducibility of a given substance is taken to be the quantity of heat which, in an infinite solid, formed of this substance, and enclosed between two parallel planes, flows during unit of time across unit of surface, taken on any intermediate plane whatever, parallel to the external planes, the distance between which is equal to unit of length, one of them being maintained at temperature 1, and the other at temperature 0 This constant flow of the heat which crosses the whole extent of the prism is denoted by the coefficient K, and is the measure of the conductivity

planes are maintained, one at the temperature g, and the other at temperature 0, the constant flow of heat, in this second hypothesis, or the quantity which during unit of time crosses unit of surface taken on an intermediate plane parallel to the bases, is equal to the product of the first flow multiplied by g

In fact, since all the temperatures have been increased in the ratio of 1 to g, the differences of the temperatures of any two points whatever m and μ, are increased in the same ratio Hence, according to the principle of the communication of heat, in order to ascertain the quantity of heat which m sends to μ

e quantity which the same

would be true for any two

which crosses a plane M

results from the sum of all the actions which the points m, m', m'', m''', etc, situated on the same side of the plane, exert on the points μ, μ', μ'', μ''', etc, situated on the other side Hence, if in the first hypothesis the constant flow is denoted by K, it will be equal to gK, when we have multiplied all the temperatures by g

137 THEOREM II *In a prism whose constant temperatures are expressed by the equation* $v = A - ax - by - cz$, *and which is bounded by six planes at right angles all of whose points are maintained at constant temperatures determined by the preceding equation, the quantity of heat which, during unit of time, crosses unit of surface taken on any intermediate plane whatever perpendicular to z, is the same as the constant flow in a solid of the same substance would be, if enclosed between two infinite parallel planes, and for which the equation of constant temperatures is* $v = c - cz$

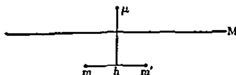


Fig 4

. v denotes the actual temperature of the point whose co-ordinates are x, y, z, A, a, b, c, are constant coefficients

To prove this proposition, consider in the solid any three points whatever $mM\mu$, situated on the same straight line $m\mu$, which the point M divides into two equal parts, denote by x, y, z the co-ordinates of the point M, and its temperature by v, the co-ordinates of the point μ by $x+\alpha$, $y+\beta$, $z+\gamma$, and its temperature by w, the co-ordinates of the point m by $x-\alpha$, $y-\beta$, $z-\gamma$, and its temperature by u, we shall have

$$v = A - ax - by - cz,$$
$$w = A - a(x+\alpha) - b(y+\beta) - c(z+\gamma),$$
$$u = A - a(x-\alpha) - b(y-\beta) - c(z-\gamma),$$

whence we conclude that,

$$v - w = a\alpha + b\beta + c\gamma, \text{ and } u - v = a\alpha + b\beta + c\gamma;$$

therefore $$v - w = u - v$$

Now the quantity of heat which one point receives from another depends on the distance between the two points and on the difference of their temperatures Hence the action of the point M on the point μ is equal to the action of m on M, thus the point M receives as much heat from m as it gives up to the point μ

We obtain the same result, whatever be the direction and magnitude of the line which passes through the point M, and is divided into two equal parts Hence it is impossible for this point to change its temperature, for it receives from all parts as much heat as it gives up

The same reasoning applies to all other points, hence no change can happen in the state of the solid

133 COROLLARY I A solid being enclosed between two infinite parallel planes A and B, if the actual temperature of its different points is supposed to be expressed by the equation $v = 1 - z$, and the two planes which bound it are maintained by any cause whatever, A at the temperature 1, and B at the temperature 0, this particular case will then be included in the preceding theorem, if we make $A = 1$, $a = 0$, $b = 0$, $c = 1$

134 COROLLARY II *If in the interior of the same solid we imagine a plane* M parallel to those which bound it, we see that a certain quantity of heat flows across this plane during unit of time, for two very near points, such as m and n, one of which is below the plane and the other above it, are unequally heated, the first, whose temperature is highest, must therefore send to the second, during each instant, a certain quantity of heat which, in some cases, may be very small and even insensible, according to the nature of the body and the distance of the two molecules

[illegible] the plane [illegible] heat, and [illegible] across the plane, composes a continual flow whose value does not change, since all the molecules preserve their temperatures It is easy to prove *that this flow, or the quantity of heat which crosses the plane M during the unit of time, is equivalent to that which crosses, during the same time, another plane N parallel to the first* In fact, the part of the mass which is enclosed between the two surfaces M and N will receive continually, across the plane M, as much heat as it loses across

the plane N If the quantity of heat, which in passing the plane M enters the part of the mass which is considered, were not equal to that which escapes by the opposite surface N, the solid enclosed between the two surfaces would acquire fresh heat, or would lose a part of that which it has, and its temperatures would not be

135

to be th

and enclosed between two parallel planes, flows during unit of time across unit of surface, taken on any intermediate plane whatever, parallel to the external planes, the distance between which is equal to unit of length, one of them being maintained at temperature 1, and the other at temperature 0 This constant flow of the heat which crosses the whole extent of the prism is denoted by the coefficient K, and is the measure of the conductivity

136 LEMMA *If we suppose all the temperatures of the solid in question under the preceding article, to be multiplied by any number whatever g, so that the equation of temperatures is* $v=g-gz$, *instead of being* $v=1-z$, *and if the two external planes are maintained, one at the temperature g, and the other at temperature* 0, *the constant flow of heat, in this second hypothesis, or the quantity which during unit of time crosses unit of surface taken on an intermediate plane parallel to the bases, is equal to the product of the first flow multiplied by g*

In fact, since all the temperatures have been increased in the ratio of 1 to g, the differences of the temperatures of any two points whatever m and μ, are increased in the same ratio Hence according to the principle of the communication of heat, in order to ascertain the quantity of heat which m sends to μ

results from the sum of all the actions which the points m, m', m'', m''', etc, situated on the same side of the plane, exert on the points μ, μ', μ'', μ''', etc, situated on the other side Hence, if in the first hypothesis the constant flow is denoted by K, it will be equal to gK, when we have multiplied all the temperatures by g

137 THEOREM II *In a prism whose constant temperatures are expressed by the equation* $v=A-ax-by-cz$ *and which is bounded by six planes at right angles all of whose points are maintained at constant temperatures determined by the preceding equation, the quantity of heat which, during unit of time, crosses unit of surface taken on any intermediate plane whatever perpendicular to z, is the same as the constant flow in a solid of the same substance would be, if enclosed between two infinite parallel planes, and for which the equation of constant temperatures is* $v=c-cz$

To prove this, let us consider in the prism, and also in the infinite solid, two extremely near points m and μ separated by the plane M perpendicular to the axis of z, μ being above the plane, and m below it (see Fig 4), and below the

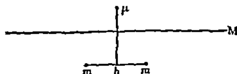


Fig 4

v denotes the actual temperature of the point whose co-ordinates are x, y, z, A, a, b, c, are constant coefficients

To prove this proposition, consider in the solid any three points whatever $mM\mu$, situated on the same straight line $m\mu$, which the point M divides into two equal parts, denote by x, y, z the co-ordinates of the point M, and its temperature by v, the co-ordinates of the point μ by $x+\alpha$, $y+\beta$, $z+\gamma$, and its temperature by w, the co-ordinates of the point m by $x-\alpha$, $y-\beta$, $z-\gamma$, and its temperature by u, we shall have

$$v=A-ax-by-cz,$$
$$w=A-a(x+\alpha)-b(y+\beta)-c(z+\gamma),$$
$$u=A-a(x-\alpha)-b(y-\beta)-c(z-\gamma),$$

whence we conclude that,

$$v-w=a\alpha+b\beta+c\gamma, \text{ and } u-v=a\alpha+b\beta+c\gamma;$$

therefore $$v-w=u-v$$

Now the quantity of heat which one point receives from another depends on the distance between the two points and on the difference of their temperatures Hence the action of the point M on the point μ is equal to the action of m on M, thus the point M receives as much heat from m as it gives up to the point μ

We obtain the same result, whatever be the direction and magnitude of the line which passes through the point M, and is divided into two equal parts Hence it is impossible for this point to change its temperature, for it receives

ɔen

133 COROLLARY I A solid being enclosed between two infinite parallel planes A and B, if the actual temperature of its different points is supposed to be expressed by the equation $v=1-z$, and the two planes which bound it are maintained by any cause whatever, A at the temperature 1, and B at the temperature 0, this particular case will then be included in the preceding theorem, if we make $A=1$, $a=0$, $b=0$, $c=1$

134 COROLLARY II If in the interior of the same solid we imagine a plane M parallel to those which bound it, we see that a certain quantity of heat flows across this plane during unit of time, for two very near points, such as m and n, one of which is below the plane and the other above it, are unequally heated, the first, whose temperature is highest, must therefore send to the second, during each instant, a certain quantity of heat which, in some cases, may be very small, and even insensible, according to the nature of the body and the distance of the two molecules

The same is true for any two other points whatever separated by the plane That which is most heated sends to the other a certain quantity of heat, and the sum of these partial actions, or of all the quantities of heat sent across the plane, composes a continual flow whose value does not change, since all the molecules preserve their temperatures It is easy to prove *that this flow, or the quantity of heat which crosses the plane M during the unit of time, is equivalent*

nd

oss

and enclosed between two parallel planes, flows during unit of time across unit of surface, taken on any intermediate plane whatever, parallel to the external planes, the distance between which is equal to unit of length, one of them being maintained at temperature 1, and the other at temperature 0 This

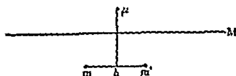
the preceding article, to be multiplied by any number whatever g, so that the equation of temperatures is $v=g-gz$, instead of being $v=1-z$, and if the two external planes are maintained, one at the temperature g, and the other at temperature 0, the constant flow of heat, in this second hypothesis, or the quantity which during unit of time crosses unit of surface taken on an intermediate plane parallel to the bases, is equal to the product of the first flow multiplied by g

In fact, since all the temperatures have been increased in the ratio of 1 to g, the differences of the temperatures of any two points whatever m and μ, are increased in the same ratio Hence, according to the principle of the communication of heat, in order to ascertain the quantity of heat which m sends to μ on the second hypothesis, we must multiply by g the quantity which the same point m sends to μ on the first hypothesis The same would be true for any two other points whatever Now, the quantity of heat which crosses a plane M

peratures by g

the preceding equation, the quantity of heat which, during unit of time, crosses unit of surface taken on any intermediate plane whatever perpendicular to z, is the same as the constant flow in a solid of the same substance would be, if enclosed between two infinite parallel planes, and for which the equation of constant temperatures is $v=c-cz$.

To prove this, let us consider in the prism, and also in the infinite solid, two extremely near points m and μ, separated by the plane M perpendicular to the axis of z; μ being above the plane, and m below it (see Fig. 4), and below the



v denotes the actual temperature of the point whose co-ordinates are x, y, z, A, a, b, c, are constant coefficients

To prove this proposition, consider in the solid any three points whatever $mM\mu$, situated on the same straight line $m\mu$, which the point M divides into two equal parts, denote by x, y, z the co-ordinates of the point M, and its temperature by v, the co-ordinates of the point μ by $x+\alpha$, $y+\beta$, $z+\gamma$, and its temperature by w, the co-ordinates of the point m by $x-\alpha$, $y-\beta$, $z-\gamma$, and its temperature by u, we shall have

$$v=A-ax-by-cz,$$
$$w=A-a(x+\alpha)-b(y+\beta)-c(z+\gamma),$$
$$u=A-a(x-\alpha)-b(y-\beta)-c(z-\gamma),$$

whence we conclude that

$$v-w=a\alpha+b\beta+c\gamma, \text{ and } u-v=a\alpha+b\beta+c\gamma;$$

therefore $$v-w=u-v$$

Now the quantity of heat which one point receives from another depends on the distance between the two points and on the difference of their temperatures Hence the action of the point M on the point μ is equal to the action of m on M, thus the point M receives as much heat from m as it gives up to the point μ

We obtain the same result, whatever be the direction and magnitude of the line which passes through the point M, and is divided into two equal parts Hence it is impossible for this point to change its temperature, for it receives from all parts as much heat as it gives up

The same reasoning applies to all other points, hence no change can happen in the state of the solid

133 COROLLARY I A solid being enclosed between two infinite parallel planes A and B, if the actual temperature of its different points is supposed to be expressed by the equation $v=1-z$, and the two planes which bound it are maintained by any cause whatever, A at the temperature 1, and B at the temperature 0, this particular case will then be included in the preceding theorem, if we make $A=1$, $a=0$, $b=0$, $c=1$

134 COROLLARY II If in the interior of the same solid we imagine a plane M parallel to those which bound it, we see that a certain quantity of heat flows across this plane during unit of time, for two very near points, such as m and n, one of which is below the plane and the other above it, are unequally heated, the first, whose temperature is highest, must therefore send to the second, during each instant, a certain quantity of heat which, in some cases, may be very small, and even insensible, according to the nature of the body and the distance of the two molecules

The same is true for any two other points whatever separated by the plane That which is most heated sends to the other a certain quantity of heat, and the sum of these partial actions, or of all the quantities of heat sent across the plane, composes a continual flow whose value does not change, since all the molecules preserve their temperatures It is easy to prove *that this flow, or the quantity of heat which crosses the plane M during the unit of time, is equivalent to that which crosses, during the same time, another plane N parallel to the first* In fact, the part of the mass which is enclosed between the two surfaces M and N will receive continually, across the plane M, as much heat as it loses across

139 The propositions which we have proved in the preceding articles apply also to the case in which the instantaneous action of a molecule is exerted in [illegible]

All observation concurs to prove that in solids and liquids the distance in question is extremely small

140 THEOREM III If the temperatures at the points of a solid are expressed by the equation $v=f(x, y, z, t)$, in which x, y, z are the co-ordinates of a molecule whose temperature is equal to v after the lapse of a time t, the flow of heat which crosses part of a plane traced in the solid, perpendicular to one of the three axes, is no longer constant, its value is different for different parts of the plane, and it varies also with the time This variable quantity may be determined by analysis

Let ω be an infinitely small circle whose centre coincides with the point m of the solid, and whose plane is perpendicular to the vertical co ordinate z, during the instant dt there will flow across this circle a certain quantity of heat which will pass from the part of the circle below the plane of the solid into the upper part This flow is composed of all the rays of heat which depart from a lower point and arrive at an upper point, by crossing a point of the small surface ω We proceed to shew *that the expression of the value of the flow is* $-K\frac{dy}{dz}\omega dt$

[illegible]

temperature w of a molecule infinitely near to m, we shall have the linear equation

$$w=v'+\xi\frac{dv'}{dx}+\eta\frac{dv'}{dy}+\zeta\frac{dv'}{dz}$$

The coefficients $v', \frac{dv'}{dx}, \frac{dv'}{dy}, \frac{dv'}{dz}$ are the values which are found by substituting in the functions $v, \frac{dv}{dx}, \frac{dv}{dy}, \frac{dz}{dz}$, for the variables x, y, z, the constant [illegible] of the point m from the first

[illegible]

prism, enclosed between six planes perpendicular to the three axes whose origin is m, that is the actual temperature of each molecule of this prism, whose dimensions are finite, is expressed by the linear equation $w=A+a\xi+b\eta+c\zeta$, and that the six faces which bound the prism are maintained at the fixed temperatures which the last equation assigns to them The state of the *internal molecules will also be permanent, and a quantity of heat measured by* the expression $-Kc\omega dt$ will flow during the instant dt across the circle ω

This arranged, if we take as the values of the constants A, a, b, c, the quantities $v', \frac{dv'}{dx}, \frac{dv'}{dy}, \frac{dv'}{dz}$, the fixed state of the prism will be expressed by the equation

$$w=v'+\frac{dv'}{dx}\xi+\frac{dv'}{dy}\eta+\frac{dv'}{dz}\zeta.$$

Thus the molecules infinitely near to the point m will have, during the instant dt, the same actual temperature in the solid whose state is variable, and in the prism whose state is constant. Hence the flow which exists at the point m, during the instant dt, across the infinitely small circle ω, is the same in either solid, it is therefore expressed by $-K\frac{dv'}{dz}\omega dt$

From this we derive the following proposition

If in a solid whose internal temperatures vary with the time, by virtue of the

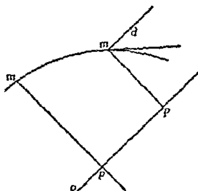


Fig 5

to the line, the quantity of heat which has flowed during the instant dt, across this circle, in the direction in which the abscissæ op increase, will be measured by the product of four factors, which are, the tangent of the angle α, a constant coefficient K, the area ω of the circle, and the duration dt of the instant

141 COROLLARY If we represent by ϵ the abscissa of this curve or the distance of a point p of the straight line from a fixed point o, and by v the ordinate which represents the temperature of the point p, v will vary with the distance ϵ and will be a certain function $f(\epsilon)$ of that distance, the quantity of heat which would flow across the circle ω, placed at the point p perpendicular to the line, will be $-K\frac{dv}{d\epsilon}\omega dt$, or

$$-Kf'(\epsilon)\omega dt,$$

denoting the function $\frac{df(\epsilon)}{d\epsilon}$ by $f'(\epsilon)$

We may express this result in the following manner, which facilitates its application

To obtain the actual flow of heat at a point p of a straight line drawn in a solid whose temperatures vary by action of the molecules, we must divide the difference of the temperatures at two points infinitely near to the point p by the distance between these points The flow is proportional to the quotient

142 THEOREM IV. From the preceding Theorems it is easy to deduce the general equations of the propagation of heat

Suppose the different points of a homogeneous solid of any form whatever, to have received initial temperatures which vary successively by the effect of the mutual action of the molecules, and suppose the equation $v=f(x, y, z, t)$ to represent the successive states of the solid, it may now be shewn that v a function of four variables necessarily satisfies the equation

$$\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2}\right)$$

In fact, let us consider the movement of heat in a molecule enclosed between six planes at right angles to the axes of x, y, and z, the first three of these planes pass through the point m whose coordinates are x, y, z, the other three pass through the point m', whose coordinates are $x+dx$, $y+dy$, $z+dz$

During the instant dt, the molecule receives, across the lower rectangle $dxdy$, which passes through the point m, a quantity of heat equal to $-K\,dx\,dy\,\frac{dv}{dz}\,dt$. To obtain the quantity which escapes from the molecule by the opposite face, it is sufficient to change z into $z+dz$ in the preceding expression, that is to say, to add to this expression its own differential taken with respect to z only, we then have

$$-K\,dx\,dy\frac{dv}{dz}dt - K\,dx\,dy\,\frac{d\left(\frac{dv}{dz}\right)}{dz}\,dz\,dt$$

as the value of the quantity which escapes across the upper rectangle The same molecule receives also across the first rectangle $dz\,dx$ which passes through the point m, a quantity of heat equal to $-K\frac{dv}{dy}\,dz\,dx\,dt$, and if we add to this expression its own differential taken with respect to y only, we find that the quantity which escapes across the opposite face $dz\,dx$ is expressed by

$$-K\frac{dv}{dy}\,dz\,dx\,dt - K\,\frac{d\left(\frac{dv}{dy}\right)}{dy}\,dy\,dz\,dx\,dt$$

Lastly, the molecule receives through the first rectangle $dy\,dz$ a quantity of heat equal to $-K\frac{dv}{dx}\,dy\,dz\,dt$, and that which it loses across the opposite rectangle which passes through m' is expressed by

$$-K\frac{dv}{dx}\,dy\,dz\,dt - K\,\frac{d\left(\frac{dv}{dx}\right)}{dx}\,dx\,dy\,dz\,dt$$

We must now take the sum of the quantities of heat which the molecule receives and subtract from it the sum of those which it loses Hence it appears that during the instant dt, a total quantity of heat equal to

$$K\left(\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2}\right)dx\,dy\,dz\,dt$$

accumulates in the interior of the molecule It remains only to obtain the increase of temperature which must result from this addition of heat

Thus the molecules infinitely near to the point m will have, during the instant dt, the same actual temperature in the solid whose state is variable, and in the prism whose state is constant Hence the flow which exists at the point m, during the instant dt, across the infinitely small circle ω, is the same in either solid, it is therefore expressed by $-K\frac{dv'}{dz}\omega dt$

From this we derive the following proposition

If in a solid whose internal temperatures vary with the time, by virtue of the

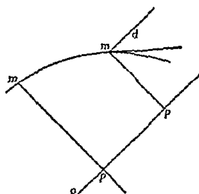


Fig 5

to the line, the quantity of heat which has flowed during the instant dt, across this circle, in the direction in which the abscissæ op increase, will be measured by the product of four factors, which are, the tangent of the angle α, a constant coefficient K, the area ω of the circle, and the duration dt of the instant

141 COROLLARY If we represent by ϵ the abscissa of this curve or the distance of a point p of the straight line from a fixed point o, and by v the ordinate which represents the temperature of the point p, v will vary with the distance ϵ and will be a certain function $f(\epsilon)$ of that distance, the quantity of heat which would flow across the circle ω, placed at the point p perpendicular to the line, will be $-K\frac{dv}{d\epsilon}\omega dt$, or

$$-Kf'(\epsilon)\omega dt,$$

denoting the function $\frac{df(\epsilon)}{d\epsilon}$ by $f'(\epsilon)$

We may express this result in the following manner, which facilitates its application

To obtain the actual flow of heat at a point p of a straight line drawn in a solid whose temperatures vary by action of the molecules, we must divide the difference of the temperatures at two points infinitely near to the point p by the distance between these points The flow is proportional to the quotient

We proceed to examine, in the following articles, the nature of the equation which expresses this third condition

Consider the variable state of a solid whose heat is dispersed into air, maintained at the fixed temperature 0 Let ω be an infinitely small part of the external surface, and μ a point of ω, through which a normal to the surface is drawn, different points of this line have at the same instant different temperatures

Let v be the actual temperature of the point μ, taken at a definite instant, and w the corresponding temperature of a point ν of the solid taken on the normal, and distant from μ by an infinitely small quantity α Denote by x, y, z *the co-ordinates of the point* μ, *and those of the point* ν *by* $x+\delta x$, $y+\delta y$,

$=0$, we shall have

$$mdx+ndy+pdz=0,$$

m, n, p being functions of x, y, z

It follows from the corollary enunciated in Article 141, that the flow in direction of the normal, or the quantity of heat which during the instant dt would cross the surface ω, if it were placed at any point whatever of this line,

$$-K\frac{w-v}{\alpha}\omega dt,$$

K denoting the specific conducibility of the mass On the other hand, the surface ω permits a quantity of heat to escape into the air, during the time dt, equal to $hv\omega dt$, h being the conductivity relative to atmospheric air Thus the flow of heat at the end of the normal has two different expressions, that is to say

$$hv\omega dt \text{ and } -K\frac{w-v}{\alpha}\omega dt,$$

hence these two quantities are equal, and it is by the expression of this equality that the condition relative to the surface is introduced into the analysis

147 We have

$$w=v+\delta v=v+\frac{dv}{dx}\delta x+\frac{dv}{dy}\delta y+\frac{dv}{dz}\delta z$$

Now *it follows from the principles of geometry*, that the co-ordinates δx, δy, δz, which fix the position of the point ν of the normal relative to the point μ satisfy the following conditions

$$p\delta x=m\delta z, \quad p\delta y=n\delta z$$

We have therefore

$$w-v\frac{1}{p}\left(m\frac{dv}{dx}+n\frac{dv}{dy}+p\frac{dv}{dz}\right)\delta z\cdot$$

we have also

$$\alpha=\sqrt{\delta x^2+\delta y^2+\delta z^2}=\frac{1}{p}\left(m^2+n^2+p^2\right)^{\frac{1}{2}}\delta z,$$

D being the density of the solid, or the weight of unit of volume, and C the specific capacity, or the quantity of heat which raises the unit of weight from the temperature 0 to the temperature 1, the product $CD\,dx\,dy\,dz$ expresses the quantity of heat required to raise from 0 to 1 the molecule whose volume is $dx\,dy\,dz$ Hence dividing by this product the quantity of heat which the molecule has just acquired, we shall have its increase of temperature Thus we obtain the general equation

$$\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2}\right) \qquad \text{(A)},$$

which is the equation of the propagation of heat in the interior of all solid bodies

143 *Independently of this equation the system of temperatures is often subject to several definite conditions of which no general expression can be given since they depend on the nature of the problem*

If the dimensions of the mass in which heat is propagated are finite, and if the surface is maintained by some special cause in a given state *for example*, if all its points retain, by virtue of that cause the constant temperature 0, we shall have denoting the unknown function v by $\phi\ (x, y, z, t)$, the equation of condition $\phi(x, y, z\ t) = 0$ which must be satisfied by all values of x, y, z which belong to points of the external surface whatever be the value of t Further if we suppose the initial temperatures of the body to be expressed by the known function $F(x\ y, z)$, we have also the equation $\phi(x\ y, z\ 0) = F(x, y, z)$ the condition expressed by this equation must be fulfilled by all values of the co-ordinates $x, y\ z$ which belong to any point whatever of the solid

144 Instead of submitting the surface of the body to a constant temperature we may suppose the temperature not to be the same at different points of the surface and that it varies with the time according to a given law, which is what takes place in the problem of terrestrial temperature In this case the equation relative to the surface contains the variable t

145 In order to examine by itself and from a very general point of view, the problem of the propagation of heat the solid whose initial state is given must be supposed to have all its dimensions infinite no special condition disturbs then the diffusion of heat, and the law to which this principle is submitted becomes more manifest, it is expressed by the general equation

$$\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{dv^2}{dz^2}\right),$$

to which must be added that which relates to the initial arbitrary state of the solid

Suppose the initial temperature of a molecule, whose co-ordinates are $x, y\ z$, to be a known function $F(x\ y\ z)$ and denote the unknown value v by $\phi(x\ y\ z\ t)$ we shall have the definite equation $\phi(x, y, z\ 0) = F(x\ y\ z)$, thus the problem is reduced to the integration of the general equation (A) in such a manner that it may agree, when the time is zero, with the equation which contains the arbitrary function F

SECTION VII *General Equation Relative to the Surface*

146 *If the solid has a definite form and if its original heat is dispersed gradually into atmospheric air maintained at a constant temperature*, a third condition relative to the state of the surface must be added to the general equation (A) and to that which represents the initial state

We proceed to examine in the following articles the nature of the equation which expresses this third condition

Consider the variable state of a solid whose heat is dispersed into air maintained at the fixed temperature 0 Let ω be an infinitely small part of the external surface, and μ a point of ω through which a normal to the surface is drawn, different points of this line have at the same instant different temperatures

Let v be the actual temperature of the point μ, taken at a definite instant, and w the corresponding temperature of a point ν of the solid taken on the normal, and distant from μ by an infinitely small quantity α Denote by x, y z the co-ordinates of the point μ, and those of the point ν by $x+\delta x$, $y+\delta y$,

$=0$, we shall have

$$mdx+ndy+pdz=0,$$

m, n, p being functions of x, y, z

It follows from the corollary enunciated in Article 141, that the flow in direction of the normal, or the quantity of heat which during the instant dt would cross the surface ω, if it were placed at any point whatever of this line,

$$-K\frac{w-v}{\alpha}\omega dt,$$

K denoting the specific conducibility of the mass On the other hand the surface ω permits a quantity of heat to escape into the air, during the time dt, equal to $hv\omega dt$, h being the conductivity relative to atmospheric air Thus the flow of heat at the end of the normal has two different expressions, that is to say

$$hv\omega dt \text{ and } -K\frac{w-v}{\alpha}\omega dt,$$

hence these two quantities are equal, and it is by the expression of this equality that the condition relative to the surface is introduced into the analysis

147 We have

$$w=v+\delta v-v+\frac{dv}{dx}\delta x+\frac{dv}{dy}\delta y+\frac{dv}{dz}\delta z$$

Now it follows from the principles of geometry, that the co-ordinates δx δy, δz, which fix the position of the point ν of the normal relative to the point μ satisfy the following conditions

$$p\delta x-m\delta z, \quad p\delta y=n\delta z$$

We have therefore

$$w-v\frac{1}{p}\left(m\frac{dv}{dx}+n\frac{dv}{dy}+p\frac{dv}{dz}\right)\delta z$$

we have also

$$\alpha=\sqrt{\delta x^2+\delta y^2+\delta z^2}=\frac{1}{p}(m^2+n^2+p^2)^{\frac{1}{2}}\delta z,$$

or $\alpha = \frac{q}{p}\delta z$, denoting by q the quantity $(m^2+n^2+p^2)^{\frac{1}{2}}$,

hence $$\frac{w-v}{\alpha} = \left(m\frac{dv}{dx} + n\frac{dv}{dy} + p\frac{dv}{dz}\right)\frac{1}{q},$$

consequently the equation

$$h v \omega dt = -K\left(\frac{w-v}{\alpha}\right)\omega dt$$

becomes the following

$$m\frac{dv}{dx} + n\frac{dv}{dy} + p\frac{dv}{dz} + \frac{h}{K}vq = 0 \qquad \text{(B)}$$

This equation is definite and applies only to points at the surface it is t which must be added to the general equation of the propagation of heat (and to the condition which determines the initial state of the solid, m, n, p are known functions of the co-ordinates of the points on the surface

148 The equation (B) signifies in general that *the decrease of the temp ture in the direction of the normal at the boundary of the solid, is such t the quantity of heat which tends to escape by virtue of the action of the m cules is equivalent always to that which the body must lose in the medi*

The mass of the solid might be imagined to be prolonged, in such a man that the surface, instead of being exposed to the air, belonged at the same t *to the body which it bounds and to the mass of a solid envelope which c* tained it If, on this hypothesis any cause whatever regulated at every inst the decrease of the temperatures in the solid envelope, and determined i *such a manner that the condition expressed by the equation (B) was alw* satisfied the action of the envelope would take the place of that of the air, a the movement of heat would be the same in either case we can suppose th that this cause exists, and determine on this hypothesis the variable state the solid which is what is done in the employment of the two equations (and (B)

By this it is seen how the interruption of the mass and the action of medium, disturb the diffusion of heat by submitting it to an accidental con tion

149 We may also consider the equation (B), which relates to the state of surface, under another point of view but we must first derive a remarka *consequence from Theorem III (Art 140) We retain the construction* ferred to in the corollary of the same theorem (Art 141) Let x, y, z be t co-ordinates of the point p, and

$$x+\delta x \quad y+\delta y, \; z+\delta z$$

those of a point q infinitely near to p, and taken on the straight line in qu tion if we denote by v and u the temperatures of the two points p and q tak at the same instant, we have

$$w = v + \delta v = v + \frac{dv}{dx}\delta x + \frac{dv}{dy}\delta y + \frac{dv}{dz}\delta z,$$

hence the quotient

$$\frac{\delta v}{\delta \epsilon} = \frac{dv}{dx}\frac{\delta x}{\delta \epsilon} + \frac{dv}{dy}\frac{\delta y}{\delta \epsilon} + \frac{dv}{dz}\frac{\delta z}{\delta \epsilon}, \text{ and } \delta\epsilon = \sqrt{\delta x^2 + \delta y^2 + \delta z^2};$$

thus the quantity of heat which flows across the surface ω placed at the point p, perpendicular to the straight line, is

$$-K\omega dt\left\{\frac{dv}{dx}\,\frac{\delta x}{\delta\epsilon}+\frac{dv}{dy}\,\frac{\delta y}{\delta\epsilon}+\frac{dv}{dz}\,\frac{\delta z}{\delta\epsilon}\right\}.$$

The first term is the product of $-K\dfrac{dv}{dx}$ by dt and by $\omega\dfrac{\delta x}{\delta\epsilon}$ The latter quantity is, according to the principles of geometry, the area of the projection of ω on the plane of y and z, thus the product represents the quantity of heat which would flow across the area of the projection, if it were placed at the point p perpendicular to the axis of x

The second term $-K\dfrac{dv}{dy}\,\omega\dfrac{\delta y}{\delta\epsilon}\,dt$ represents the quantity of heat which would cross the projection of ω, made on the plane of x and z, if this projection were placed parallel to itself at the point p

Lastly, the third term $-K\dfrac{dv}{dz}\,\omega\dfrac{\delta z}{\delta\epsilon}\,dt$ represents the quantity of heat which would flow during the instant dt, across the projection of ω on the plane of x and y, if this projection were placed at the point p, perpendicular to the coordinate z

By this it is seen *that the quantity of heat which flows across every infinitely small part of a surface drawn in the interior of the solid, can always be decomposed into three other quantities of flow, which penetrate the three orthogonal projections of the surface, along the directions perpendicular to the planes of the projections* The result gives rise to properties analogous to those which have been noticed in the theory of forces

150 The quantity of heat which flows across a plane surface ω, infinitely

that the heat which is in fact accumulated in it, and makes its temperature vary, cannot be expressed except by terms infinitely smaller than those of the first order

its three projections would receive

In other respects it is necessary that this should be so for, if one of the

is contrary to experience

151 We proceed to apply this remark to a molecule situated at the external surface of the solid

Through a point a (see Fig 6), taken on the plane of x and y draw two planes perpendicular, one to the axis of x the other to the axis of y Through a point b of the same plane, infinitely near to a, draw two other planes parallel to the two preceding planes, the ordinates z, raised at the points a, b, c, d, up to the

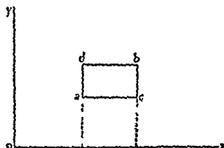


Fig 6

external surface of the solid, will mark on this surface four points a', b', c', d', and will be the edges of a truncated prism, whose base is the rectangle $abcd$ If through the point a' which denotes the least elevated of the four points a', b', c', d', a plane be drawn parallel to that of x and y, it will cut off from the truncated prism a molecule, one of whose faces that is to say $a'b'c'd'$, coincides with the surface of the solid The values of the four ordinates aa', cc', dd', bb' are the following

$$aa'=z,$$

$$cc'=z+\frac{dz}{dx}dx,$$

$$dd'=z+\frac{dz}{dy}dy,$$

$$bb'=z+\frac{dz}{dx}dx+\frac{dz}{dy}dy$$

152 One of the faces perpendicular to x is a triangle, and the opposite face is a trapezium The area of the triangle is

$$\tfrac{1}{2}dy\frac{dz}{dy}dy,$$

and the flow of heat in the direction perpendicular to this surface being $-K\frac{dv}{dx}$ we have, omitting the factor dt

$$-K\frac{dv}{dx}\tfrac{1}{2}dy\frac{dz}{dy}dy,$$

as the expression of the quantity of heat which in one instant passes into the molecule, across the triangle in question

The area of the opposite face is

$$\tfrac{1}{2}dy\left(\frac{dz}{dx}dx+\frac{dz}{dx}dx+\frac{dz}{dy}dy\right),$$

and the flow perpendicular to this face is also $-K\frac{dv}{dx}$, suppressing terms of the

second order infinitely smaller than those of the first, subtracting the quantity of heat which escapes by the second face from that which enters by the first we find

$$K\frac{dv}{dx}\,\frac{dz}{dx}\,dx\,dy$$

This term expresses the quantity of heat the molecule receives through the faces perpendicular to x

It will be found, by a similar process, that the same molecule receives, through the faces perpendicular to y, a quantity of heat equal to $K\frac{dv}{dy}\frac{dz}{dy}dx\,dy$

The quantity of heat which the molecule receives through the rectangular base is $-K\frac{dv}{dz}dx\,dy$ Lastly, across the upper surface $a'b'c'd'$, a certain quantity of heat is permitted to escape, equal to the product of hv into the extent ω of that surface The value of ω is, according to known principles, the same as that of $dx\,dy$ multiplied by the ratio $\frac{\epsilon}{z}$, ϵ denoting the length of the normal between the external surface and the plane of x and y, and

$$\epsilon=z\left\{1+\left(\frac{dz}{dx}\right)^2+\left(\frac{dz}{dy}\right)^2\right\}^{\frac{1}{2}},$$

hence the molecule loses across its surface $a'b'c'd'$ a quantity of heat equal to $hv\,dx\,dy\frac{\epsilon}{z}$

Now, the terms of the first order which enter into the expression of the total quantity of heat acquired by the molecule, must cancel each other, in order that the variation of temperature may not be at each instant a finite quantity, *we must then have the equation*

$$K\left(\frac{dv}{dx}\,\frac{dz}{dx}\,dx\,dy+\frac{dv}{dy}\,\frac{dz}{dy}\,dx\,dy-\frac{dv}{dz}\,dx\,dy\right)-hv\frac{\epsilon}{z}\,dx\,dy=0,$$

$$\text{or}\quad \frac{h}{K}v\frac{\epsilon}{z}=\frac{dv}{dx}\,\frac{dz}{dx}+\frac{dv}{dy}\,\frac{dz}{dy}-\frac{dv}{dz}$$

153 Substituting for $\frac{dz}{dx}$ and $\frac{dz}{dy}$ their values derived from the equation

$$m\,dx+n\,dy+p\,dz=0,$$

and denoting by q the quantity

$$(m^2+n^2+p^2),$$

we have

$$K\left(m\frac{dv}{dx}+n\frac{dv}{dy}+p\frac{dv}{dz}\right)+hvq=0 \qquad \text{(B)},$$

thus we know distinctly what is represented by each of the terms of this equation

Taking them all with contrary signs and multiplying them by $dx\,dy$, the first expresses how much heat the molecule receives through the two faces perpendicular to x, the second how much it receives through its two faces perpen-

dicular to y, the third how much it receives through the face perpendicula: z, and the fourth how much it receives from the medium The equation th fore expresses that the sum of all the terms of the first order is zero, and t the heat acquired cannot be represented except by terms of the second or

154 To arrive at equation (B), we in fact consider one of the molecu whose base is in the surface of the solid, as a vessel which receives or loses h through its different faces The equation signifies that all the terms of the f order which enter into the expression of the heat acquired cancel each oth so that the gain of heat cannot be expressed except by terms of the sec order We may give to the molecule the form, either of a right prism whose a is normal to the surface of the solid, or that of a truncated prism, or any fo whatever

The general equation (A), (Art 142) supposes that all the terms of the f order cancel each other in the interior of the mass, which is evident for p matic molecules enclosed in the solid The equation (B), (Art 147) expres the same result for molecules situated at the boundaries of bodies

Such are the general points of view from which we may look at this part the theory of heat

The equation $\frac{dv}{dt} = \frac{K}{CD}\left(\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2}\right)$ represents the movement of h in the interior of bodies It enables us to ascertain the distribution from inst to instant in all substances solid or liquid, from it we may derive the equat which belongs to each particular case

In the two following articles we shall make this application to the probl of the cylinder, and to that of the sphere

SECTION VIII *Application of the General Equations*

155 Let us denote the variable radius of any cylindrical envelope by r, a suppose, as formerly, in Article 118, that all the molecules equally distant fro the axis have at each instant a common temperature, v will be a function o and t, r is a function of y, z, given by the equation $r^2 = y^2 + z^2$ It is evident the first place that the variation of v with respect to x is nul, thus the term $\frac{d}{d}$ must be omitted We shall have then, according to the principles of the diffe ential calculus, the equations

$$\frac{dv}{dy} = \frac{dv}{dr}\,\frac{dr}{dy} \text{ and } \frac{d^2v}{dy^2} = \frac{d^2v}{dr^2}\left(\frac{dr}{dy}\right)^2 + \frac{dv}{dr}\left(\frac{d^2r}{dy^2}\right),$$

$$\frac{dv}{dz} = \frac{dv}{dr}\,\frac{dr}{dz} \text{ and } \frac{d^2v}{dz^2} = \frac{d^2v}{dr^2}\left(\frac{dr}{dz}\right)^2 + \frac{dv}{dr}\left(\frac{d^2r}{dz^2}\right),$$

whence

$$\frac{d^2v}{dy^2} + \frac{d^2v}{dz^2} = \frac{d^2v}{dr^2}\left\{\left(\frac{dr}{dy}\right)^2 + \left(\frac{dr}{dz}\right)^2\right\} + \frac{dv}{dr}\left(\frac{d^2r}{dy^2} + \frac{d^2r}{dz^2}\right) \qquad (a)$$

In the second member of the equation, the quantities

$$\frac{dr}{dy},\ \frac{dr}{dz},\ \frac{d^2r}{dy^2},\ \frac{d^2r}{dz^2},$$

must be replaced by their respective values, for which purpose we derive from the equation $y^2+z^2=r^2$,

$$y=r\frac{dr}{dy} \text{ and } 1=\left(\frac{dr}{dy}\right)^2+r\frac{d^2r}{dy^2},$$

$$z=r\frac{dr}{dz} \text{ and } 1=\left(\frac{dr}{dz}\right)^2+r\frac{d^2r}{dz^2},$$

and consequently

$$y^2+z^2=r^2\left\{\left(\frac{dr}{dy}\right)^2+\left(\frac{dr}{dz}\right)^2\right\},$$

$$2=\left(\frac{dr}{dy}\right)^2+\left(\frac{dr}{dz}\right)^2+r\left\{\frac{d^2r}{dy^2}+\frac{d^2r}{dz^2}\right\}$$

The first equation, whose first member is equal to r^2, gives

$$\left(\frac{dr}{dy}\right)^2+\left(\frac{dr}{dz}\right)^2=1 \qquad (b),$$

the second gives, when we substitute for

$$\left(\frac{dr}{dy}\right)^2+\left(\frac{dr}{dz}\right)^2$$

its value 1,

$$\frac{d^2r}{dy^2}+\frac{d^2r}{dz^2}=\frac{1}{r} \qquad (c)$$

If the values given by equations (b) and (c) be now substituted in (a), we have

$$\frac{d^2v}{dy^2}+\frac{d^2v}{dz^2}=\frac{d^2v}{dr^2}+\frac{1}{r}\frac{dv}{dr}$$

Hence the equation which expresses the movement of heat in the cylinder, is

$$\frac{dv}{dt}=\frac{K}{CD}\left(\frac{d^2v}{dr^2}+\frac{1}{r}\frac{dv}{dr}\right)$$

as was found formerly, Art 119

We might also suppose that particles equally distant from the centre have not received a common initial temperature, in this case we should arrive at a much more general equation

156 To determine, by means of equation (A), the movement of heat in a sphere which has been immersed in a liquid, we shall regard v as a function of r and t, r is a function of x, y, z, given by the equation

$$r^2=x^2+y^2+z^2,$$

r being the variable radius of an envelope We have then

$$\frac{dv}{dx}=\frac{dv}{dr}\frac{dr}{dx} \text{ and } \frac{d^2v}{dx^2}=\frac{d^2v}{dr^2}\left(\frac{dr}{dx}\right)^2+\frac{dv}{dr}\frac{d^2r}{dx^2},$$

$$\frac{dv}{dy}=\frac{dv}{dr}\frac{dr}{dy} \text{ and } \frac{d^2v}{dy^2}=\frac{d^2v}{dr^2}\left(\frac{dr}{dy}\right)^2+\frac{dv}{dr}\frac{d^2r}{dy^2},$$

$$\frac{dv}{dz} = \frac{dv}{dr}\frac{dr}{dz} \text{ and } \frac{d^2v}{dz^2} = \frac{d^2v}{dr^2}\left(\frac{dr}{dz}\right)^2 + \frac{dv}{dr}\frac{d^2r}{dz^2}$$

Making these substitutions in the equation

$$\frac{dv}{dt} = \frac{K}{CD}\left\{\frac{d^2v}{dx^2} + \frac{d^2v}{dy^2} + \frac{d^2v}{dz^2}\right\},$$

we shall have

$$\frac{dv}{dt} = \frac{K}{CD}\left[\frac{d^2v}{dr^2}\left\{\left(\frac{dr}{dx}\right)^2 + \left(\frac{dr}{dy}\right)^2 + \left(\frac{dr}{dz}\right)^2\right\} + \frac{dv}{dr}\left\{\frac{d^2r}{dx^2} + \frac{d^2r}{dy^2} + \frac{d^2r}{dz^2}\right\}\right] \quad (a)$$

The equation $x^2+y^2+z^2=r^2$ gives the following results

$$x = r\frac{dr}{dx} \text{ and } 1 = \left(\frac{dr}{dx}\right)^2 + r\frac{d^2r}{dx^2},$$

$$y = r\frac{dr}{dy} \text{ and } 1 = \left(\frac{dr}{dy}\right)^2 + r\frac{d^2r}{dy^2},$$

$$z = r\frac{dr}{dz} \text{ and } 1 = \left(\frac{dr}{dz}\right)^2 + r\frac{d^2r}{dz^2}$$

The three equations of the first order give

$$x^2+y^2+z^2 = r^2\left\{\left(\frac{dr}{dx}\right)^2 + \left(\frac{dr}{dy}\right)^2 + \left(\frac{dr}{dz}\right)^2\right\}$$

The three equations of the second order give

$$3 = \left(\frac{dr}{dx}\right)^2 + \left(\frac{dr}{dy}\right)^2 + \left(\frac{dr}{dz}\right)^2 + r\left\{\frac{d^2r}{dx^2} + \frac{d^2r}{dy^2} + \frac{d^2r}{dz^2}\right\}$$

and substituting for

$$\left(\frac{dr}{dx}\right)^2 + \left(\frac{dr}{dy}\right)^2 + \left(\frac{dr}{dz}\right)^2$$

its value 1, we have

$$\frac{d^2r}{dx^2} + \frac{d^2r}{dy^2} + \frac{d^2r}{dz^2} = \frac{2}{r}$$

Making these substitutions in the equation (a) we have the equation

$$\frac{dv}{dt} = \frac{K}{CD}\left\{\frac{d^2v}{dr^2} + \frac{2}{r}\frac{dv}{dr}\right\},$$

which is the same as that of Art 114

The equation would contain a greater number of terms, if we supposed molecules equally distant from the centre not to have received the same initial temperature

We might also deduce from the definite equation (B), the equations which express the state of the surface in particular cases, in which we suppose solids of given form to communicate their heat to the atmospheric air, but in most cases these equations present themselves at once, and their form is very simple, when the co-ordinates are suitably chosen

SECTION IX *General Remarks*

157 The investigation of the laws of movement of heat in solids now consists in the integration of the equations which we have constructed, this is the *object of the following chapters* We conclude this chapter with general remarks on the nature of the quantities which enter into our analysis

In order to measure these quantities and express them numerically, they [illegible]

have chosen the quantity of heat which raises a given volume of a certain substance from the temperature 0 to the temperature 1 The choice of this unit would have been preferable in many respects to that of the quantity of heat required to convert a mass of ice of a given weight, into an equal mass of water at 0, without raising its temperature We have adopted the last unit only because it had been in a manner fixed beforehand in several works on physics, besides this supposition would introduce no change into the results of analysis

158 The specific elements which in every body determine the measurable effects of heat are three in number, namely, the conductivity proper to the body, the conductivity relative to the atmospheric air, and the capacity for heat *The numbers which express these quantities are, like the specific* gravity, so many natural characters proper to different substances

We have already remarked, Art 36, that the conductivity of the surface would be measured in a more exact manner, if we had sufficient observations on the effects of radiant heat in spaces deprived of air

It may be seen, as has been mentioned in the first section of Chapter I, Art 11, that only three specific coefficients, K, h, C, enter into the investigation, they must be determined by observation, and we shall point out in the sequel the experiments adapted to make them known with precision

159 The number C which enters into the analysis, is always multiplied by

heat, *the quantity required to raise from temperature 0 to temperature 1* unit of volume of a given substance, and not unit of weight of that substance

With the view of not departing from the common definition, we have referred the capacity for heat to the weight and not to the volume, but it would be preferable to employ the coefficient c which we have just defined, magnitudes measured by the unit of weight would not then enter into the analytical expressions we should have to consider only, 1st, the linear dimension x, the temperature v, and the time t, 2nd, the coefficients c, h, and K The three first quantities are undetermined, and the three others are, for each substance, constant elements which experiment determines *As to the unit of surface and* the unit of volume, they are not absolute, but depend on the unit of length

160 It must now be remarked that every undetermined magnitude or [illegible]

order to make our definitions more exact, and to serve to verify [illegible]

it is derived from primary notions on quantities, for which reason, in geometry and mechanics, it is the equivalent of the fundamental lemmas which the Greeks have left us without proof

161 In the analytical theory of heat, every equation (E) expresses a necessary relation between the existing magnitudes x, t, v, c, h, K This relation depends in no respect on the choice of the unit of length, which from its very nature is contingent, that is to say, if we took a different unit to measure the linear dimensions, the equation (E) would still be the same Suppose then the unit of length to be changed, and its second value to be equal to the first divided by m Any quantity whatever x which in the equation (E) represents a certain line ab, and which, consequently, denotes a certain number of times the unit of length, becomes mx, corresponding to the same length ab, the value t of the time, and the value v of the temperature will not be changed, the same is not the case with the specific elements h, K, c the first, h, becomes $\frac{h}{m^2}$, for it expresses the quantity of heat which escapes, during the unit of time, from the unit of surface at the temperature 1 If we examine attentively the nature of the coefficient K, as we have defined it in Articles 68 and 135, we perceive that it becomes $\frac{K}{m}$, for the flow of heat varies directly as the area of the surface, and inversely as the distance between two infinite planes (Art 72) As to the coefficient c which represents the product CD, it also depends on the unit of length and becomes $\frac{c}{m^3}$, hence equation (E) must undergo no change when we write mx instead of x, and at the same time $\frac{K}{m}$, $\frac{h}{m^2}$, $\frac{c}{m^3}$, instead of K, h, c, the number m disappears after these substitutions thus the dimension of x with respect to the unit of length is 1, that of K is -1, that of h is -2 and that of c is -3 If we attribute to each quantity its own *exponent of dimension*, the equation will be homogeneous, since every term will have the same total exponent Numbers such as S, which represent surfaces or solids, are of two dimensions in the first case, and of three dimensions in the second Angles, sines and other trigonometrical functions, logarithms or exponents of powers, are, according to the principles of analysis, *absolute* numbers which do not change with the unit of length, their dimensions must therefore be taken equal to 0, which is the dimension of all abstract numbers

If the unit of time, which was at first 1, becomes $\frac{1}{n}$, the number t will become nt, and the numbers x and v will not change The coefficients K, h, c will become $\frac{K}{n}$, $\frac{h}{n}$, c Thus the dimensions of x, t, v with respect to the unit of time are 0, 1, 0, and those of K, h, c are -1, -1, 0

If the unit of temperature be changed, so that the temperature 1 becomes that which corresponds to an effect other than the boiling of water, and if that effect requires a less temperature, which is to that of boiling water in the ratio of 1 to the number p, v will become vp, x and t will keep their values, and the coefficients K, h, c will become $\frac{K}{p}$, $\frac{h}{p}$, $\frac{c}{p}$.

The following table indicates the dimensions of the three undetermined quantities and the three constants, with respect to each kind of unit.

Quantity or Constant	*Length*	*Duration*	*Temperature*
Exponent of dimension of x	1	0	0
" " " " t	0	1	0
" " " " v	0	0	1
The specific conductibility, K	-1	-1	-1
The surface conductibility, h	-2	-1	-1
The capacity for heat, c	-3	0	-1

162 If we retained the coefficients C and D, whose product has been represented by c, we should have to consider the unit of weight, and we should find that the exponent of dimension, with respect to the unit of length, is -3 for the density D, and 0 for C

On applying the preceding rule to the different equations and their transformations, it will be found that they are homogeneous with respect to each kind of unit, and that the dimension of every angular or exponential quantity is nothing If this were not the case, some error must have been committed in the analysis, or abridged expressions must have been introduced.

If, for example, we take equation (b) of Art 105,

$$\frac{dv}{dt} = \frac{K}{CD}\frac{d^2v}{dx^2} - \frac{hl}{CDS}v,$$

we find that, with respect to the unit of length, the dimension of each of the three terms is 0, it is 1 for the unit of temperature, and -1 for the unit of time

In the equation $v = Ae^{-x\sqrt{\frac{2h}{Kl}}}$ of Art 76, the linear dimension of each term is 0, and it is evident that the dimension of the exponent $x\sqrt{\frac{2h}{Kl}}$ is always nothing, whatever be the units of length time, or temperature

EXPERIMENTAL RESEARCHES
IN ELECTRICITY

BIOGRAPHICAL NOTE

MICHAEL FARADAY, 1791-1867

FARADAY was born September 22, 1791, in Newington, Surrey, the son of a blacksmith When he was five, the family moved to London, and he grew up in such poverty that, as he later recalled, the loaf of bread his mother gave him had to last a week. "My education," he wrote, "was of the most ordinary description, consisting of little more than the rudiments of reading, writing, and arithmetic at a common day school My hours out of school were passed at home and in the streets"

At the age of twelve he became an errand boy for a bookseller and bookbinder, and a year later he was accepted because of exemplary conduct as an apprentice without fee His scientific education began while he was engaged in binding books As he later wrote to a friend "It was in those books, in the hours after work, that I found the beginning of my philosophy There were two that especially helped me, the [illegible]

[illegible] my foundation in that science With what money he could spare he bought materials for experiments, and by 1812 was conducting investigations in electrolytic decomposition In the spring of that year, through the generosity of a customer, he was able to attend a series of four lectures by Sir Humphry Davy at the Royal Institution He took careful notes, wrote them out in fuller form, and bound them into a book. He sent the notes to Davy with a request for employment at the Royal Institution in any capacity connected with science Davy advised him not to give up a skilled trade for something in which there was neither security, money, nor opportunity for advancement, but a few months later, on the dismissal of a laboratory assistant, he offered the post to Fara- [illegible]

tion, Faraday continued as Davy's assistant and began research of his own In 1816 he made his first contribution in the form of an analysis of caustic lime from Tuscany, which was published in the *Quarterly Journal of Science* From that time he wrote an increasing number of notes and memoirs In 1821 he began work upon electromagnetism, he first collected and repeated all the known experiments, published an account of them in the *Annals of Philosophy*, and proceeded to make his own investigations His experiments were meticulously recorded in numbered paragraphs, and in 1831 he started the first section of his *Experimental Researches in Electricity*, which was to occupy him intermittently for the next twenty three years First published in the form of monographs in the "*Transactions of the Royal Society*," they were later brought out in three volumes (*1844, 1847, 1855*)

Faraday was occupied during these years with many things in addition to research in electricity Pursuing the chemical investigations he had begun as Davy's assistant, he made a special study of chlorine, discovered two new chlorides of carbon, initiated experi- [illegible]

[illegible] of glass He [illegible]

supervision of the lighthouses of England In 1823 he was elected to the Royal Society over Davy's strong opposition, which, however, Faraday did not permit to interfere with their

grees and scientific tributes from all parts of the world, and both the Royal Society and the Royal Institution tried in vain to persuade him to accept the presidency As he told his friend Tyndall in refusing the Royal Society s offer, "I must remain plain Michael Faraday to the last"

After he had become famous for his discoveries Faraday's services were eagerly sought by industry and commerce For a few years he did a little "professional business" as he called it, and in 1830 received more than a thousand pounds in return It is estimated that this work might easily have yielded five thousand pounds in 1832, but he then felt, as he later told Tyndall, that he had to decide whether to make wealth or science the pursuit of his life He chose science and lived and died a poor man.

Faraday married in 1821, "an event," he wrote, "which more than any other contributed to my earthly happiness and healthful state of mind." The marriage was childless but Faraday's lodgings in the Royal Institution were always full of his wife's nieces and nephews, for he enjoyed the company of children and liked to take part in their games Faraday's parents belonged to the small dissident Presbyterian sect known as Sandemanians, and Faraday himself attended their meetings from childhood he made a formal declaration of faith at thirty and for two different periods discharged the office of elder

Faraday s last years were spent in seriously declining health As early as 1841, as a result of overwork he had suffered a serious breakdown and was compelled to take a complete rest for a period of several years Although he was back in the laboratory by 1845 and for fifteen years engaged in some of his most important research his health was never completely restored When at length he found his memory failing and his powers declining he yielded to others whatever parts of his work he could no longer accomplish according to his own standard of efficiency Queen Victoria in 1858 provided him with a house at Hampton Court which had rooms so arranged that he had no stairs to climb In 1862 he delivered his last lecture and performed his last experiment He died August 25, 1867

CONTENTS

PREFACES FROM ORIGINAL THREE VOLUME EDITION

Preface to Volume I

I HAVE been induced by various circumstances to collect in one volume the Fourteen Series of *Experimental Researches in Electricity*, which have appeared in the *Philosophical Transactions* during the last seven years the chief reason has been the desire to supply at a moderate price the whole of these papers, with an index, to those who may desire to have them

The readers of the volume will, I hope, do me the justice to remember that it was not written as a *whole*, but in parts, the earlier portions rarely having a

t

h

considered a faithful reprint or statement of the course and results of the whole investigation, which only—I desired to supply

degree of consistency and apparent general accuracy which they seem to me to present

I have made some alterations in the text, but they have been altogether of a

all distinguished from the Original Notes of the *Researches* by the date of Dec 1838

had to them

tances have induced me to affix a date at the top

by

hor

na-

Before concluding these lines I would beg leave to make a reference or two, first, to my own "Papers on Electro magnetic Rotations" in the *Quarterly Journal of Science*, 1822 XII, 74, 186, 283, 416, and also to my "Letter on Magneto-electric Induction" in the *Annales de Chimie*, LI, p 404 These might, as to the matter, very properly have appeared in this volume, but they would have interfered with it as a simple reprint of the *Experimental Researches* of the *Philosophical Transactions*

Then I wish to refer, in relation to the Fourth Series on a new law of Electric Conduction, to Franklin's experiments on the non-conduction of ice, which have been very properly separated and set forth by Professor Bache (*Journal of the Franklin Institute*, 1836 XVII, 183) These, which I did not at all remember as to the extent of the effect, though they in no way anticipate the expression of the law I state as to the general effect of liquefaction on electrolytes, still should never be forgotten when speaking of that law as applicable to the case of water

There are two papers which I am anxious to refer to, as corrections or criticisms of parts of the *Experimental Researches* The first of these is one by Jacobi (*Philosophical Magazine*, 1838 XIII, 401), relative to the possible production of a spark on completing the junction of the two metals of a single pair of plates (915) It is an excellent paper, and though I have not repeated the experiments, the description of them convinces me that I must have been in error The second is by that excellent philosopher Marianini (*Memoria della Societa Italiana di Modena*, XXI, 205), and is a critical and experimental examination of Series VIII, and of the question whether metallic contact is or is not *productive* of a part of the electricity of the voltaic pile I see no reason as yet to alter the opinion I have given, but the paper is so very valuable, comes to the question so directly, and the point itself is of such great importance, that I intend at the first opportunity renewing the inquiry, and, if I can, rendering the proofs either on the one side or the other undeniable to all

Other parts of these researches have received the honour of critical attention from various philosophers, to all of whom I am obliged, and some of whose corrections I have acknowledged in the foot notes There are, no doubt, occasions on which I have not felt the force of the remarks, but time and the progress of science will best settle such cases, and, although I cannot honestly say that I *wish to be found in error*, yet I do fervently hope that the progress of science in the hands of its many zealous present cultivators will be such, as by giving us new and other developments, and laws more and more general in their applications, will even make me think that what is written and illustrated in these experimental researches, belongs to the by-gone parts of science

MICHAEL FARADAY

Royal Institution, March, 1839

Preface to Volume II

FOR reasons stated in the former volume of *Experimental Researches in Electricity*, I have been induced to gather the remaining Series together, and to add to them certain other papers devoted to Electrical research

To the prefatory remarks containing these reasons, I would recall the recollection of those who may honour these *Researches* with any further attention

I have printed the papers in this volume, as before, with little or no alteration, except that I have placed the fair and just date of each at the top of the pages

I regret the presence of those papers which partake of a controversial character, but could not help it some of them contain much new, important and explanatory matter The introduction of matter due to other parties than myself, as Nobili and Antinori, or Hare, was essential to the comprehension of the further development given in the replies

I owe many thanks to the Royal Society, to Mr Murray, and to Mr Taylor for the great kindness I have received in the loan of plates, &c , and in other facilities granted to me for the printing of the volume

As the Index belongs both to the *Experimental Researches* and to the miscellaneous papers its references are of necessity made in two ways, those to the *Researches* are, as before to the numbers of the Paragraphs and are easily recognised by the greatness of the numbers the other references are to the pages, and being always preceded by *p* or *pp* are known by that mark

MICHAEL FARADAY

Preface to Volume III

To the prefatory remarks containing these reasons I would recall the recollection of those who may honour these *Researches* with any further attention I have printed the papers in this volume as before with little or no alteration, except that I have placed the fair and just date of each at the top of the pages

As regards magnecrystallic action, which commences at paragraph 2454, the

obtained

With respect to paragraph 2967, and the intentions there expressed of

measure the result, is so great as to have prevented me as yet from obtaining any results worthy of confidence

I owe many thanks to the Royal Society and to the Proprietors of the *Philosophical Magazine*, for the great kindness I have received in the loan of plates &c , and in other facilities granted to me for the printing of the volume

[1] Marchand and Scheerer say that bismuth is expanded by pressure and has its structure changed Gmelin s Handbook iv p 428

As the Index belongs both to the *Experimental Researches* and to the other papers, its references are of necessity made in two ways those to the *Researches* are, as before, to the numbers of the paragraphs, and are easily recognized by the greatness of the numbers the other references are to the pages, and being always preceded by *p* or *pp*, are known by that mark

January, 1855

MICHAEL FARADAY

FIRST SERIES

§ 1 *On the Induction of Electric Currents* § 2 *On the Evolution of Electricity from Magnetism* § 3 *New Electrical Condition of Matter* § 4 *Explication of* Arago's *Magnetic Phenomena*

READ NOVEMBER 24 1831

1 THE power which electricity of tension possesses of causing an opposite electrical state in its vicinity has been expressed by the general term Induction which as it has been received into scientific language may also with propriety be used in the same general sense to express the power which electrical currents may possess

pose using it in the present paper

2 Certain effects of the induction of electrical currents have already been recognised and described as those of magnetization Ampère s experiments of bringing a copper disc near to a flat spiral his repetition with electro-magnets of Arago s extraordinary experiments and perhaps a few others Still it appeared unlikely that these could be all the effects which induction by currents could produce espe-

in motion

3 Further Whether Ampère s beautiful theory were adopted or any other or whatever reservation were mentally made still it ap-

should not have any current induced through them or some sensible effect produced equivalent in force to such a current

4 These considerations with their consequence the hope of obtaining electricity from ordinary magnetism have stimulated me at various times to investigate experimentally the inductive effect of electric currents I lately arrived at positive results and not only had my hopes fulfilled but obtained a key which appeared to me to open out a full explanation of Arago s magnetic phenomena and also to discover a new state which may probably have great influence in some of the most important effects of electric currents

5 These results I purpose describing not as they were obtained but in such a manner as to give the most concise view of the whole

§ 1 *On the Induction of Electric Currents*

helices were superposed each containing an

eter needle could be observed

eight feet but whether the current from the trough was passed through the copper or the iron helix no effect upon the [illegible] could be perceived at the gal

9 In these and many [illegible]ents

no difference in action of any kind appeared between iron and other metals

10 Two hundred and three feet of copper wire *in one length were coiled round a large block of wood, other two hundred and three* feet of similar wire were interposed as a spiral between the turns of the first coil, and metallic contact everywhere prevented by twine One of these helices was connected with a galvanometer, and the other with a battery of one hundred pairs of plates four inches square, with double coppers, and well charged When *the contact was made, there was a sudden and very slight effect at the galvanometer, and* there was also a similar slight effect when the contact with the battery was broken But whilst the voltaic current was continuing to pass through the one helix, no galvanometrical appearances nor any effect like induction upon the other helix could be perceived, although the active power of the battery was proved to be great, *by its heating the whole of its own helix, and by the brilliancy of the discharge when made through charcoal*

11 Repetition of the experiments with a battery of one hundred and twenty pairs of plates produced no other effects, but it was ascertained, both at this and the former time, that the slight deflection of the needle occurring at the moment of completing the connexion, was always in one direction, and that the equally slight deflection produced when the *contact was broken, was in the other direction, and also, that these effects occurred when the first helices were used* (6, 8)

12 The results which I had by this time obtained with magnets *led* me to believe that the battery current through one wire, did in reality, induce a similar current through the other wire, but that it continued for an instant only, and partook more of the nature of the electrical wave passed through from the shock of a *common* Leyden jar *than of the current from a* voltaic battery, and therefore might magnetise *a steel needle, although it scarcely affected the galvanometer*

13 *This expectation was confirmed for on substituting a small hollow helix, formed round* a glass tube, *for the galvanometer, introducing* a steel needle, making contact as before between the battery and the inducing wire (7, 10), and then removing the needle before the battery contact was broken, it was found magnetised.

14 When the battery contact was first made, then an unmagnetised needle introduced into the small indicating helix (13), and lastly the battery contact broken, the needle was found magnetised to an equal degree apparently as before, *but the poles were of the contrary kind*

15 *The same effects* took place on using the large compound helices first described (6 8)

16 When the unmagnetised needle was put into the indicating helix, before contact of the inducing wire with the battery, and remained there until the contact was broken, it exhibited little or no magnetism the first effect having been nearly neutralised by the second (13, 14) *The force of the induced current upon making contact was found always to exceed that of the* induced current at breaking of contact, *and if* therefore the contact was made and broken many times in succession, whilst the needle remained in the indicating helix, it at last came out not unmagnetised, but a needle magnetised as if the induced current upon making contact had acted alone on it This effect may be due to the accumulation (as it is called) *at the poles of the unconnected pile, rendering the current upon first making contact* more powerful than what it is *afterwards,* at the moment of breaking contact

17 If the circuit between the helix or wire under induction and the galvanometer or indicating spiral was not rendered complete *before* the connexion between the battery and the inducing wire was completed or broken, then no effects were perceived at the galvanometer Thus, *if the battery communications were first made, and then the wire under induction connected with the indicating helix, no magnetising power was there exhibited But still retaining the latter communications, when those* with the battery were broken, a magnet was formed in the helix, but of the second kind (14), i e, with poles indicating a current in the same direction to that belonging to the battery current, or to that always induced by that current *at its cessation*

18 In the preceding experiments the wires were placed near to each other, and the contact of the inducing one with the battery made *when the inductive effect was required, but as the particular action might be supposed to be exerted only at the moments of making and breaking contact, the induction was produced* in another way *Several feet of copper wire* were stretched in wide zigzag *forms, representing the letter W,* on one surface of a broad board, a second wire was stretched in precisely similar forms on a second board, so that when brought near the first, the wires should every-

where touch, except that a sheet of thick paper was interposed One of these wires was connected with the galvanometer, and the other with a voltaic battery The first wire was then moved towards the second, and as it approached, the needle was deflected Being then removed, the needle was deflected in the opposite direction By first making the wires approach and then recede, simultaneously with the vibrations of the needle, the latter soon became very extensive, but when the wires ceased to move from or towards each other, the galvanometer-needle soon came to its usual position

19 As the wires approximated, the induced current was in the *contrary* direction to the inducing current As the wires receded, the induced current was in the *same* direction as the inducing current When the wires remained stationary, there was no induced current (54)

20 When a small voltaic arrangement was introduced into the circuit between the galvanometer (10) and its helix or wire, so as to cause a permanent deflection of 30° or 40°, and then the battery of one hundred pairs of plates connected with the inducing wire, there was an instantaneous action as before (11), but the galvanometer-needle immediately resumed and retained its place unaltered, notwithstanding the continued contact of the inducing wire with the trough such was the case in whichever way the contacts were made (33)

21 Hence it would appear that collateral currents, either in the same or in opposite directions, exert no permanent inducing power on each other, affecting their quantity or tension

22 I could obtain no evidence by the tongue, [illegible]

23 This deficiency of effect is not because the induced current of electricity cannot pass fluids, but probably because of its brief duration and feeble intensity, for on introducing two large copper plates into the circuit on the induced side (20), the plates being immersed through a voltaic trough (20). When, however, the quantity of interposed fluid was reduced to a drop, the galvanometer gave no indication

24 Attempts to obtain similar effects by the use of wires conveying ordinary electricity were doubtful in the results A compound helix sim- [illegible]

by wire, and the two general terminations thus produced connected with the small magnetising helix containing an unmagnetised needle (13) The other four helices were similarly arranged, but their ends connected with a Leyden jar On passing the discharge, the needle was found to be a magnet, but it appeared probable that a part of the electricity of the jar had passed off to the small helix, and so magnetised the needle There was indeed no reason to expect that the electricity of a jar possessing as it does great tension, would not diffuse itself through all the metallic matter interposed between the coatings

25 Still it does not follow that the discharge of ordinary electricity through a wire does not produce analogous phenomena to those arising from voltaic electricity, but as it appears impossible to separate the effects produced at the moment when the discharge begins to pass, [illegible]

in this form of the experiment they can be perceived

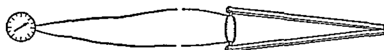
[illegible]

The result is the production of other currents, (but which are only momentary), parallel, or tending to parallelism, with the inducing cur- [illegible]

[illegible]

wire, after induction has developed the

PLATE I


Fig 2

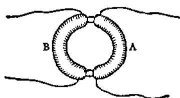


Fig 1

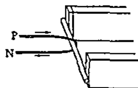
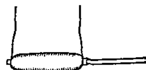
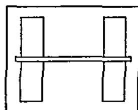
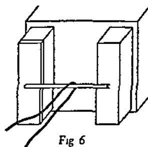
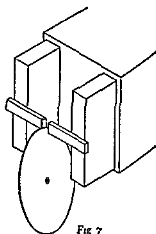


Fig 3


Fig 4


Fig 5


Fig 6


Fig 7

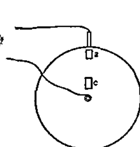
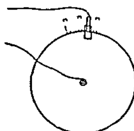


Fig 10


Fig 9

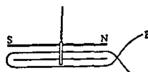


Fig 8

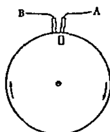


Fig 11

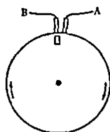


Fig. 12

current, and whilst the electricity from the battery continues to flow through its inducing neighbour (10, 18), constitute a peculiar electric condition, the consideration of which will be resumed hereafter (60) All these results have been obtained with a voltaic apparatus consisting of a single pair of plates

§ 2 *On the Evolution of Electricity from Magnetism*

27 A welded ring was made of soft round bar iron, the metal being seven-eighths of an inch in thickness, and the ring six inches in external diameter Three helices were put round one part of this ring, each containing about twenty-four feet of copper wire one-twentieth of an inch thick, they were insulated from the iron and each other, and superposed in the manner before described (6), occupying about nine inches in length upon the ring They could be

the helices of A, but being separated from it at each extremity by about half an inch of the uncovered iron

28 The helix B was connected by copper wires with a galvanometer three feet from the ring The helices of A were connected end to end so as to form one common helix, the extremities of which were connected with a battery of ten pairs of plates four inches square The galvanometer was immediately affected, and to a degree far beyond what has been described when with a battery of tenfold power helices *without iron* were used (10), but though the contact was continued, the effect was not permanent, for the needle soon came to rest in

passed, similar but rather more powerful effects were produced

30 When the battery contact was made in one direction, the galvanometer needle was deflected on the one side, if made in the other direction, the deflection was on the other side The deflection on breaking the battery contact was always the reverse of that produced by completing it The deflection on making a battery contact always indicated an induced current in the opposite direction to that from the battery, but on breaking the contact the deflection indicated an induced current in the same direction as that of the battery No making or breaking of the contact at B side, or in any part of the galvanometer circuit, produced any effect at the galvanometer No continuance of the battery current caused any deflection of the galvanometer needle As the above results are common to all these experiments, and to similar ones with ordinary magnets to be hereafter detailed, they need not be again particularly described

31 Upon using the power of one hundred pairs of plates (10) with this ring the impulse at the galvanometer, when contact was com-

32 By using charcoal at the ends of the B helix, a minute *spark* could be perceived when *the contact of the battery with A was com*

obtained by using a stronger original current or a more powerful arrangement of helices

33 A feeble voltaic current was sent through the helix B and the galvanometer, so as to deflect the needle of the latter 30° or 40°, and

ever way the battery contacts were made and shows that here again (20) no permanent influence of the currents upon each other, as to their quantity and tension exists

34 Another arrangement was then employed connecting the former experiments on volta-

[1] *Platina* early form for *platinum* used often this work —Ed.

electric induction (6—26) with the present A combination of helices like that already described (6) was constructed upon a hollow cylinder of pasteboard there were eight lengths of copper wire, containing altogether 220 feet four of these helices were connected end to end, and then with the galvanometer (7) the other intervening four were also connected end to end, and the battery of one hundred pairs discharged through them In this form the effect on the galvanometer was hardly sensible (11), though magnets could be made by the induced current (13) But when a soft iron cylinder seven-eighths of an inch thick, and twelve inches long was introduced into the pasteboard tube surrounded by the helices, then the induced current affected the galvanometer powerfully and with all the phenomena just described (30) It possessed also the power of making magnets with more energy, apparently than when no iron cylinder was present

35 When the iron cylinder was replaced by an equal cylinder of copper, no effect beyond that of the helices *alone* was produced The iron cylinder arrangement was not so powerful as the ring arrangement already described (27)

36 Similar effects were then pro[illegible] y *ordinary magnets* [illegible] gen[illegible] n [illegible] copper w[illegible] in length, the soft iron cylinder was introduced into its axis a couple of bar magnets each twenty-four inches long, were arranged with their opposite poles at one end in contact, so as to resemble a horse-shoe magnet, and then contact made between the other poles and the ends of the iron cylinder, so as to convert it for the time into a magnet (Pl I *Fig* 2) by breaking the magnetic contacts, or reversing them, the magnetism of the iron cylinder could be destroyed or reversed at pleasure

37 Upon making magnetic contact the needle was deflected continuing the contact, the needle became indifferent, and resumed its first position, on breaking the contact, it was again deflected, but in the opposite direction to the first effect, and then it again became indifferent When the magnetic contacts were reversed the deflections were reversed

38 When the magnetic contact was made, the deflection was such as to indicate an [illegible] duced current of electri[illegible] rection [illegible] the [illegible] cont[illegible] mark [illegible] were placed as in Pl I, *Fig 3*, the current in the helix was in the direction represented, P being supposed to be the end of the wire going to the positive pole of the battery, or that end towards which the zinc plates face, and N the negative wire. Such a current would have converted the cylinder into a magnet of the *opposite kind* to that formed by contact with the poles A and B, and such a current moves in the opposite direction to the currents which in M Ampère's beautiful theory are considered as constituting a magnet in the *position figured* [1]

39 But as it might be supposed that in all the preceding experiments of this section, it was by some peculiar effect taking place during the formation of the magnet, and not by its *mere virtual approximation*, that the momentary induced current was excited the following experiment was made All the similar ends of the compound hollow helix (34) were bound together by copper wire, forming two general terminations, and these were connected with the galvanometer The soft iron cylinder (34) was removed and a cylindrical magnet, three-quarters of an inch in diameter and eight inches and a half in length, used instead One end of this magnet was introduced into the axis of the helix (Pl I, *Fig 4*), and then, the galvanometer needle being stationary, the magnet was suddenly thrust in immediately the needle was deflected in the same direction as if the magnet had been formed by either of the two preceding processes (34, 36) Being left in, the needle resumed its first position, and then the magnet being withdrawn the needle was deflected in the opposite direction These effects were not great but by introducing and withdrawing the magnet, so that the impulse each *time* should be added to those previously communicated to the needle, the latter could be made to vibrate through an arc of 180° or more

[1] The relative position of an electric current and a magnet is by most persons found very difficult to remember and three or four helps to the memory have been devised by M Ampère and others I venture to suggest the following as a very simple and effectual assistance in these and similar latitudes Let the experimenter think he is looking down upon a dipping needle or upon the pole of the earth and then let him think upon the direction of the motion of the hands of a watch or of a screw moving direct, currents in that direction round a needle would make it into such a magnet as the dipping needle or would themselves constitute an electro-magnet of similar qualities or if brought near a magnet would tend to make it take that direction or would themselves be moved into that position by a magnet so placed or in M Ampère's theory are considered as moving in that direction in the magnet These two points of the position of the dipping needle and the motion of the watch hands being remembered any other relation of the current and magnet can be at once deduced from it

er it be pushed quite through or withdrawn, the needle is deflected in a direction the reverse of that previously produced. When the magnet

(34) be laid east and west (or in any other constant position), and a magnet be retained east and west, its marked pole always being one way, then whichever end of the helix the

trary to that due to its entrance

42 These effects are simple consequences of the *law* hereafter to be described (114)

43 When the eight elementary helices were

guard against any direct action of the inducing magnet upon the galvanometer, and it was found that by moving the magnet in the same direction, and to the same degree on the outside of the helix, no effect on the needle was produced.

44 The Royal Society are in possession of a large compound magnet formerly belonging to Dr Gowin Knight, which, by permission of the President and Council, I was allowed to use in the prosecution of these experiments it is at present in the charge of Mr Christie, at his house at Woolwich, where, by Mr Christie's kindness, I was at liberty to work, and I have to acknowledge my obligations to him for his *assistance in all the experiments and observa-*

poles projected horizontally six inches from the box, were each twelve inches high and three inches wide They were nine inches apart, and when a soft iron cylinder, three-quarters of an inch in diameter and twelve inches long, was put across from the one to the other, it required a

force of nearly one hundred pounds to break the contact The pole to the left in the figure is the marked pole [1]

45 The indicating galvanometer, in all experiments made with this magnet, was about eight feet from it, not directly in front of the poles, but about 16° or 17° on one side It was found that on making or breaking the connexion of the poles by soft iron, the instrument was slightly affected, but all error of observation arising from this cause was easily and carefully avoided

46 The electrical effects exhibited by this magnet were very striking When a soft iron cylinder thirteen inches long was put through the compound hollow helix, with its ends arranged as two general terminations (39), these

round many times in succession [2]

47 Notwithstanding this great power, if the contact was continued, the needle resumed its natural position, being entirely uninfluenced

equal to the former

48 A piece of copper plate wrapped *once*

with the poles the galvanometer was strongly affected

49 Dismissing the helices and sockets, the galvanometer wire was passed over, and consequently only half round the iron cylinder (Pl I, *Fig* 6), but even then a strong effect upon the needle was exhibited, when the magnetic

inder, and consequently containing no metal

inductive force was of course greater, the nearer the helix, either with or without its iron cylinder, was brought to the poles, but otherwise the same effects were produced, whether the

of approximation and removal were the reverse of each other (30)

the magneto-electric induction was rendered sensibly greater

obtained with the weaker bar magnets

53 A spiral containing fourteen feet of copper wire, being connected with the galvano-

theoretically considered by M Ampère as existing in the magnet (38), or as the current in an electro-magnet of similar polarity *As the* spiral was withdrawn, the induced current was reversed

54 A similar spiral had the current of eighty pairs of 4-inch plates sent through it so as to form an electro-magnet, and then the other spiral connected with the galvanometer (53)

which will be very evident in the fourth part of this paper.

56 All attempts to obtain chemical effects by the induced current of electricity failed, though the precautions before described (22), and all others that could be thought of, were employed Neither was any sensation on the

experiments more at leisure at the Royal Institution, with an armed loadstone belonging to Professor Daniell and capable of lifting about thirty pounds, a frog was very *powerfully convulsed* each time magnetic contact was made At first the convulsions could not be obtained

convulsed strongly The more instantaneous the union or disunion is effected, the more powerful the convulsion I thought also I could perceive the *sensation* upon the tongue and the *flash* before the eyes, but I could obtain no *evidence of chemical decomposition*

57 The various experiments of this section prove, I think, most completely the production of electricity from ordinary magnetism That its intensity should be very feeble and quantity small, cannot be considered wonder-

whilst so passing possesses the peculiar magnetic actions and force of a current of electric-

produced by ferruginous electro-magnets (34), there is no doubt that arrangements like the magnets of Professors Moll, Henry, Ten Eyke, and others, in which as many as two thousand pounds have been lifted, may be used for these *experiments, in which case not only a brighter*

electric arrangements to be explained in the fourth section are excited by the powers of such apparatus

[1] For a mode of obtaining the spark from the com-

58 The similarity of action almost amount-

language is still necessary I propose to call the *agency thus exerted by ordinary magnets, magneto-electric* or *magnelectric* induction (26)

59 The only difference which powerfully strikes the attention as existing between volta electric and magneto-electric induction is the suddenness of the former, and the sensible time required by the latter, but even in this early state of investigation there are circumstances which seem to indicate that upon further inquiry this difference will, as a philosophical distinction, disappear (68)[1]

§ 3 *New Electrical State or Condition of Matter*[2]

60 Whilst the wire is subject to either volta-electric or magneto-electric induction it appears to be in a peculiar state for it resists the

mon circumstances This electrical condition of matter has not hitherto been recognised but it probably exerts a very important influence in many if not most of the phenomena produced by currents of electricity For reasons which will immediately appear (71) I have, after advising with several learned friends ventured to designate it as the *electro-tonic* state

61 This peculiar condition shows no known electrical effects whilst it continues nor have I yet been able to discover any peculiar powers exerted or properties possessed, by matter whilst retained in this state

62 It shows no reaction by attractive or repulsive powers The various experiments which

[1] For important additional phenomena and devel

electrical conductors must have acquired this state, and yet no evidence of attractive or repulsive powers has been observed I have placed copper and silver discs, very delicately suspended on torsion balances *in vacuo* near to the poles of very powerful magnets, yet have not been able to observe the least attractive or repulsive force

63 I have also arranged a fine slip of gold leaf very near to a bar of copper, the two being in metallic contact by mercury at their extremities These have been placed *in vacuo*, so that metal rods connected with the extremities of

on the outside being sometimes completed by wires, and sometimes broken But I never could obtain any sensible motion of the gold leaf, either directed to the magnet or towards the collateral bar of copper, which must have been, as far as induction was concerned, in a similar state to itself

pose in M Ampère s theory of magnetism, tend to throw doubt on such cases, for if magnetism depend upon the attraction of electrical currents, and if the powerful currents at first ex

magneto-attractive powers It seems far more probable that the extremely feeble permanent effects observed have been due to traces of iron or perhaps some other unrecognised cause not magnetic

65 This peculiar condition exerts no retard-

when masses of metal, wires, helices, &c, were arranged in all possible ways by the side of a wire or helix, carrying a current measured by the galvanometer (20), not the slightest permanent change in the indication of the instrument could be perceived *Metal in the supposed peculiar state, therefore, conducts electricity in all directions with its ordinary facility, or, in other words, its conducting power is* not sensibly altered by it

66 All metals take on the peculiar state *This is proved in the preceding experiments* with copper and iron (9), and with gold silver, tin, lead, zinc, antimony, bismuth, mercury &c, by experiments to be described in the fourth part (132), admitting of easy application *With regard to iron, the experiments* prove the thorough and remarkable independence of these phenomena of induction and the *ordinary magnetical appearances of that metal*

67 This state is altogether the effect of the induction exerted and ceases as soon as the inductive force is removed It is the same state, whether produced by the collateral passage of *voltaic currents* (26), *or the formation of a* magnet (34, 36), or the mere approximation of a magnet (39, 50), and is a strong proof in addition to those advanced by *M Ampère, of the* identity of the agents concerned in these several operations It probably occurs, momentarily, during the passage of the common electric spark (24), and may perhaps be obtained *hereafter in bad conductors by weak electrical* currents or other means (74, 76)

68 The state appears to be instantly assumed (12), requiring hardly a sensible portion of time for that purpose The *difference* of time between volta-electric and magneto-electric induction, rendered evident by the galvanometer (59), may probably be thus explained *When a voltaic current is sent throu*[illegible] two parallel wires as th[illegible] (34) [illegible] , and which, by ex[illegible] [illegible] *found to be inappreciably small* The action will seem still more instantaneous, because, as there is an accumulation of power in the poles of the battery before contact, the first rush of electricity in the wire of communication is greater than that sustained *after* the contact is completed, the wire of induction becomes at the moment electro-tonic to an equivalent degree, which *the moment after* sinks to the state in which the continuous current can sustain it, but in sinking, causes an opposite *induced current to that at first produced* The consequence is that the first induced wave of electricity more resembles that from the discharge of an electric jar than it otherwise would do

69 But when the iron cylinder is put into the same helix (34), previous to the connexion being made with the battery, then the current from the latter may be considered as active in *inducing innumerable currents of a similar kind* to itself in the iron, rendering it a magnet This is known by experiment to occupy time *for a magnet so formed, even of soft iron, does not* rise to its fullest intensity in an instant, and it may be because the currents within the iron are successive in their formation or arrangement But as the magnet can induce as well as *the battery current, the combined action of* the two continues to evolve induced electricity, until their joint effect is at a maximum, and *thus the existence of the deflecting force is prolonged* sufficiently to overcome the inertia of the galvanometer needle

70 In all those cases where the helices or wires are advanced towards or taken from the magnet (50, 55), *the direct or inverted current* of induced electricity continues for the time occupied in the advance or recession *for the electro-tonic state is rising to a higher or falling* to a lower degree during that time, and the change is accompanied by its corresponding evolution of electricity but these form no objections to the opinion that the electro-tonic *state is instantly assumed*

71 This peculiar state appears to be a state of tension, and may be considered as *equivalent to a current of electricity, at least equal to* that produced either when the condition is induced or destroyed The current evolved, however, first or last is not to be considered a measure of the degree of tension to which the *electro-tonic state has risen for* as the metal retains its conducting powers unimpaired (65), and as the electricity evolved is but *for a moment*, (the peculiar state being instantly assumed and lost (68)), the electricity which may *be led away by long wire conductors* offering obstruction in their substance proportionate to their small lateral and extensive linear dimensions, can be but a very small portion of that really evolved within the mass at the moment *it assumes this condition Insulated* helices and portions of metal instantly assumed the state and no traces of electricity could be *discovered* in them, however quickly the contact with the electrometer was made, after they *were put under induction, either by the current*

from the battery or the magnet A single drop of water or a small piece of moistened paper (23, 56) was obstacle sufficient to stop the current through the conductors, the electricity evolved returning to a state of equilibrium through the metal itself, and consequently in an unobserved manner

72 The *tension of this state may therefore* be comparatively very great But whether great or small, it is hardly conceivable that it should

in any other way as yet been able to distinguish effects attributable to such a reaction

73 All the results favour the notion that the electro-tonic state relates to the particles, and not to the mass, of the wire or substance under induction, being in that respect different to the induction exerted by electricity of tension If so, the state may be assumed in liquids when no electrical current is sensible, and even in non conductors, the current itself, when it occurs, being as it were a contingency due to the

74 The current of electricity which induces the electro-tonic state in a neighbouring wire, probably induces that state also in its own

tween the agent and the matter acted upon would be very greatly diminished A copper bolt had its extremities connected with a galvanometer, and then the poles of a battery of one hundred pairs of plates connected with the bolt, so as to send the current through it, the voltaic circuit was then suddenly broken, and the galvanometer observed for any indications of a return current through the copper bolt due to the discharge of its supposed electro-tonic state No effect of the kind was obtained, nor indeed, *for two reasons, ought it to be expected, for* first, as the cessation of induction and the discharge of the electro-tonic condition are simultaneous, and not successive, the return current would only be equivalent to the neutralization of the last portion of the inducing current, *and would not therefore show any* alteration of direction, or assuming that time did intervene, and that the latter current was really distinct from the former, its short, sudden character (12, 26) would prevent it from being thus recognised

75 No difficulty arises, I think, in considering the wire thus rendered electro-tonic by its own current more than by any external current, especially when the apparent non interference of that state with currents is considered (62, 71) The simultaneous existence of the conducting and electro-tonic states finds an analogy in the manner in which electrical currents can be passed through magnets, where it is found that both the currents passed, and those of the magnets, preserve all their properties distinct from each other, and exert their mutual actions

76 The reason given with regard to metals

assume the electro-tonic state should that

this forced state may be sufficient to make an

tinued, the electro-tonic state may be instantly

renewed, producing the forced arrangement of the compound particles, to be as instantly discharged by a transference of the elementary particles of the opposite kind in opposite directions, but parallel to the current Even the differences between common and voltaic electricity, when applied to effect chemical decomposition, which Dr Wollaston has pointed out,[1] seem explicable by the circumstances connected with the induction of electricity from these

liquid as poles, they have completed, for some time, the voltaic circuit, in consequence of which, when separated from the battery and plunged into the same fluid, they by themselves produce an electric current[3] M A Van Beek is detailed cases in which the electrical relation of one metal in contact with another has

the true relation of the former to the latter can only be decided when our knowledge of all these phenomena has been enlarged

sent through the spiral, a strong magnet at the same time being presented to the copper disc,

the latter turned at the moment to take a position of equilibrium, exactly as the spiral itself would have turned had it been free to move I have not been able to obtain this effect, nor indeed any motion, but the cause of my failure in the *latter* point may be due to the momentary existence of the current not allowing time for the inertia of the plate to be overcome (11, 12) M Ampere has perhaps succeeded in obtaining motion from the superior delicacy and power of his electro magnetical apparatus, or he may have obtained only the motion due to cessation of action But all my results tend to invert the sense of the proposition stated by M Ampère, ' that a current of electricity tends to put the electricity of conductors near which

79 The momentary existence of the phenomena of induction now described is sufficient to furnish abundant reasons for the uncertainty or failure of the experiments, hitherto made to obtain electricity from magnets, or to effect chemical decomposition or arrangement by their means[5]

80 It also appears capable of explaining fully the remarkable phenomena observed by M Arago between metals and magnets when neither are moving (120), as well as most of the

[5] *The Lycée* No 36 for January 1st has a long and rather premature article in which it endeavours to show anticipations by French philosophers of my researches It however mistakes the erroneous results of MM Fresnel and Ampère for true ones and then imagines my true results are like those errone-

afford the readiest means of obtaining electricity from magnetism, I shall now proceed to describe.

§ 4. *Explication of Arago's Magnetic Phenomena*

81. If a plate of copper be revolved close to a magnetic needle, or magnet, suspended in such a way that the latter may rotate in a plane parallel to that of the former, the magnet tends to follow the motion of the plate; or if the magnet be revolved, the plate tends to follow its motion; and the effect is so powerful, that mag-

can be observed between them (62) This is the phenomenon discovered by M. Arago; and he states that the effect takes place not only with all metals, but with solids, liquids, and even gases, i e, with all substances (130).

(from gas retorts), i e, only with excellent conductors of electricity. They refer the effect to magnetism induced in the plate by the mag-

fect to an attractive force, and is not agreed to by the discoverer, M Arago, nor by M Am-

made with a long dipping-needle, conceive the action to be always repulsive (125).

many of these were in the course of the investigation superseded by more perfect arrangements, I shall consider myself at liberty to rearrange them in a manner calculated to convey most readily what appears to me to be a correct view of the nature of the phenomena.

84. The magnet has been already described (44). To concentrate the poles, and bring them nearer to each other, two iron or steel bars,

Occasionally two bars of soft iron were em-

at pleasure.

per and lead were constructed so as to come in contact with the edge of the copper disc (85), or with other forms of plates hereafter to be

most powerful magnet, and gave terrestrial direction to the whole; Pl. I, *Fig. 8.* represents

PLATE II

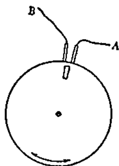


Fig 1

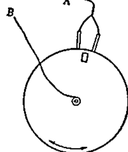


Fig 2

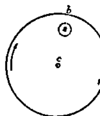


Fig 3

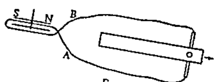


Fig 4

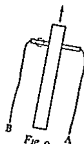


Fig 9

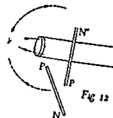


Fig 12

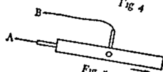


Fig 5

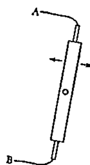


Fig 10

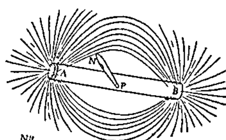


Fig 13

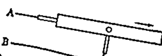


Fig 6

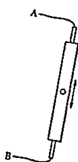


Fig 11



Fig 14

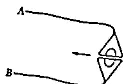


Fig 16

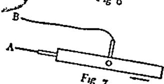


Fig 7

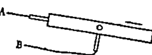


Fig 8

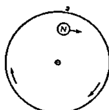
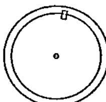


Fig 15


Fig 17

the direction of the wire and of the needles when the instrument was placed in the magnetic meridian the ends of the wires are marked A and B for convenient reference hereafter The letters S and N designate the south and north ends of the needle when affected merely by terrestrial magnetism, the end N is therefore the marked pole (44) The whole instrument was protected by a glass jar, and stood, as to position and distance relative to the large magnet, under the same circumstances as before (45)

apart, and the edge of the plate inserted about half their width between them One of the galvanometer wires was passed twice or thrice loosely round the brass axis of the plate and the other attached to a conductor (86), which itself was retained by the hand in contact with

instant the plate moved the galvanometer was influenced, and by revolving the plate quickly the needle could be deflected 90° or more

89 It was difficult under the circumstances to make the contact between the conductor and the edge of the revolving disc uniformly good and extensive, it was also difficult in the

ments were made more carefully, a permanent deflection of the needle of nearly 45° could be sustained

90 Here therefore was demonstrated the production of a permanent current of electricity by ordinary magnets (57)

91 When the motion of the disc was reversed, every other circumstance remaining the same, the galvanometer needle was deflected with equal power as before, but the deflection was on the opposite side, and the current of electricity evolved, therefore, the reverse of the former

92 When the conductor was placed on the

considerable distance, i e, 50° or 60° on each side of the place of the magnetic poles The current gathered by the conductor and conveyed to the galvanometer was of the same

netic poles, not being affected in that respect by the direction of the rotation When the rotation of the disc was reversed, the direction of the current of electricity was reversed also but the other circumstances were not affected

93 On raising the plate, so that the magnetic poles were entirely hidden from each other by its intervention, (*a*, Pl I, *Fig 10*), the same effects were produced in the same order, and with equal intensity as before On raising it still higher, so as to bring the place of the poles to *c*, still the effects were produced and apparently with as much power as at first

94 When the conductor was held against the edge as if fixed to it, and with it moved between the poles, even though but for a few degrees, the galvanometer needle moved and indicated a current of electricity, the same as that which would have been produced if the wheel had revolved in the same direction, the conductor remaining stationary

cated the difference between a strong current

equidistant from the magnetic poles, as in Pl

a current according with the direction of rotation (91), both conductors now acting consentaneously, and as a single conductor did before (88)

97 *All these effects could* be obtained when only one of the poles of the magnet was brought near to the plate, they were of the same kind as to direction, &c , but by no means so powerful

98 All care was taken to render these results independent of the earth's magnetism, or of the mutual magnetism of the magnet and galvanometer needles The contacts were made in

were taken But the absence of any interference of the kind referred to, was readily shown by the want of all effect when the disc was removed from the poles, or the poles from the disc, every other circumstance remaining the same

99 The *relation of the current* of electricity produced, to the magnetic pole, to the direction of rotation of the plate, &c , &c , may be expressed by saying, that when the unmarked

at the edge of the plate nearest to the pole is positive As the pole of the earth may mentally be considered the unmarked pole, this relation of the rotation, the pole, and the electricity evolved, is not difficult to remember Or if, in Pl II, *Fig 3*, the circle represent the copper disc revolving in the direction of the arrows, and *a* the outline of the unmarked pole placed beneath the plate, then the electricity collected at *b* and the neighbouring parts is positive, whilst that collected at the centre *c* and other parts is negative (88) The currents in the plate are therefore from the centre by the magnetic poles towards the circumference

100 *If the marked pole be placed above,* all other things remaining the same, the electricity at *b*, Pl II, *Fig 3*, is still positive If the marked pole be placed below, or the unmarked pole above, the electricity is reversed If the direction of revolution in any case is reversed,

poles in a rectilinear direction and

motion, and crossing it at the place of the magnetic pole or poles This was sufficiently shown by the following simple experiment A piece of copper plate one-fifth of an inch thick, one inch

tion of the arrow, Pl II, *Fig 4*, immediately the galvanometer needle was deflected, its north or marked end passed eastward, indicating that the wire A received negative and the wire B positive electricity, and as the marked pole was above, the result is in perfect accordance with the effect obtained by the rotatory plate (99)

102 On reversing the motion of the plate the needle at the galvanometer was deflected in the opposite direction, showing an opposite current

103 To render evident the character of the electrical current existing in various parts of the moving copper plate, differing in their re-

with the end of the plate as the most neutral

the motion of the first arrangement, that of *Fig 6* to *Fig 7*, B received negative electricity

104 When the plates were previously removed sideways from between the magnets, as in Pl II, *Fig 9*, so as to be quite out of the polar axis, still the same effects were produced, though not so strongly.

105 *When the magnetic poles* were in contact, and the copper plate was drawn between the conductors near to the place, there was but very little effect produced When the poles were opened by the width of a card, the effect was somewhat more, but still very small

much as the plates

107. If the conductors were held permanently against any particular parts of the copper

plates, and carried between the magnetic poles with them, effects the same as those described were produced, in accordance with the results obtained with the revolving disc (94)

108 On the conductors being held against the ends of the plates, and the latter then passed between the magnetic poles, in a direction transverse to their length, the same effects were produced (Pl II, *Fig 10*) The parts of the plates towards the end may be considered either as mere conductors, or as portions of metal in which the electrical current is excited, according to their distance and the strength of the magnet, but the results were in perfect harmony with those before obtained The effect was as strong as when the conductors were held against the sides of the plate (101)

109 When a mere wire, connected with the galvanometer so as to form a complete circuit, was passed through between the poles, the galvanometer was affected, and upon moving the wire to and fro, so as to make the alternate impulses produced correspond with the vibrations of the needle, the latter could be increased *to 20° or 30°* on each side *of the magnetic meridian*

110 [illegible]

nometer But the moment the motion became transverse, the needle was deflected

111 These effects were also obtained from *electro-magnetic poles*, resulting from the use of copper helices or spirals either alone or with iron cores (34, 54) The directions of the motions were precisely the same, but the action was much greater when the iron cores were used, than without

112 When a flat spiral was passed *through*

tion of its motion) acting in opposite directions and the reason why the needle went to the same side, whether the spiral passed by the poles in the one or the other direction, was

gle wires (40, 109)

113 Although the experiments with the revolving plate, wires, and plates of metal, were first successfully made with the large magnet belonging to the Royal Society, yet they were all ultimately repeated with a couple of bar magnets two feet long one inch and a half

direction of the motion

114 The relation which holds between the

Fig 12, PN represent a horizontal wire passing

¹ By magnetic curves I mean the lines of magnetic forces however modified by the juxtaposition of poles which would be depicted by iron filings or those to which a very small magnetic needle would form a tangent.

with it, the current will be from P′ to N′ If the wire be considered a tangent to the curved surface of the cylindrical magnet, and it be carried round that surface into any other position, or if the magnet itself be revolved on its axis, so as to bring any part opposite to the tangential wire—still, *if afterwards the wire be moved in the directions indicated, the current of electricity will be from P to N, or if it be moved in the opposite direction, from N to P, so that as* regards the motions of the wire past the pole, they may be reduced to two, directly opposite *to each other, one of which produces a current* from P to N, and the other from N to P

115 The same holds true of the unmarked *pole of the magnet, except that if it be substituted* for the one in the figure, then as the wires are moved in the direction of the arrows, the current of electricity would be from N to *P, and when they move in the reverse direc*tion, from P to N

116 Hence the current of electricity which is excited in metal when moving in the neighbourhood of a magnet, depends for its direction altogether upon the relation of the metal to the resultant of magnetic action, or to the magnetic curves, and may be expressed in a popular way thus Let A B (Pl II, *Fig 13*) represent a cylinder magnet, A being the marked pole, and B the unmarked pole, let P N be a silver knife-blade, resting across the magnet with its edge upward, and with its marked or notched side towards the pole A, then in whatever direction or position this knife be moved *edge foremost, either about the marked or the* unmarked pole, the current of electricity produced will be from P to N, provided the intersected curves proceeding from A abut upon the notched surface of the knife, and those from B upon the unnotched side Or if the knife be moved with its back foremost, the current will be from N to P in every possible position and direction, provided the intersected curves abut on the same surfaces as before. A little model is easily constructed, by using a cylinder of wood for a magnet, a flat piece for the blade and a piece of thread connecting one end of the cylinder with the other, and passing through a hole in the blade, for the magnetic curves this readily gives the result of any possible direction.

117 When the wire under induction is passing by an electro-magnetic pole, as for instance one end of a copper helix traversed by the electric current (34), the direction of the current in the approaching wire is the same with that of the current in the parts or sides of the spirals nearest to it, and in the receding wire the reverse of that in the parts nearest to it

118 All these results show that the power of inducing electric currents is circumferentially exerted by a magnetic resultant or axis of power, just as circumferential magnetism is dependent upon and is exhibited by an electric current

119 *The experiments described combine to* prove that when a piece of metal (and the same may be true of all conducting matter [213]) is *passed either before a single pole, or between* the opposite poles of a magnet, or near electromagnetic poles, whether ferruginous or not *electrical currents are produced across the met*al transverse to the direction of motion, and which therefore, in Arago s experiments will approximate towards the direction of radii *If a single wire be moved like the spoke* of a wheel near a magnetic pole, a current of electricity is determined through it from one end towards the other If a wheel be imagined constructed of a great number of these radii and this revolved near the pole, in the manner of the copper disc (85), each radius will have a current produced in it as it passes by the pole If the radii be supposed to be in contact laterally, a copper disc results, in which the directions of the currents will be generally the same being modified only by the coaction which can take place between the particles, now that they are in metallic contact

120 Now that the existence of these currents is known, *Arago's phenomena may be account*ed for without considering them as due to the formation in the copper, of a pole of the opposite kind to that *approximated, surrounded by* a diffuse polarity of the same kind (82), neither is it essential that the plate should acquire and *lose its state in a finite time, nor on the other* hand does it seem necessary that any repulsive *force should be admitted as the cause of the ro*tation (82)

121 The effect is precisely of the same kind as the electro-magnetic rotations which *I had the good fortune to discover* some years ago[1] According to the experiments then made which have since been abundantly confirmed, *if a* wire P N, (Pl II, *Fig 14*) be connected with the positive and negative ends of a voltaic battery, so that the positive electricity *shall pass* from P to N, and a marked magnetic pole N be placed near the wire between it and the spec-

[1] *Quarterly Journal of Science* Vol XII pp 74 186 416 283.

plate beneath a magnetic pole for let N (Pl II *Fig 15*) be a marked pole above the circular plate the latter being rotated in the direct on of the arrow immediately currents of positive electricity set from the central parts in

in the same manner moves to the r ght l and

122 If the rotation of the disc be reversed the electric currents are reversed (91) and the pole therefore moves to the left hand If the contrary pole be employed the effects are the same i e in the same direction because currents of electricity the reverse of those described are produced and by reversing both poles and currents the visible effects remain unchanged In whatever position the axis of the magnet be placed provided the same pole be applied to the same side of the plate the electric current produced is in the same direct on in consistency with the law already stated (114 &c) and thus every circumstance regarding the direction of the motion may be explained

123 These currents are *discharged or return* in the parts of the plate on each s de of and more distant from the place of the pole where

of the effect of rotation in the magnet over the plate itself

124 It is under the point of view just put

to of nos est

for the rotation) that *time* may be required for the development of the maximum current in

allel to the plane of rotation and the other perpendicular to it the former would be the force exerted in making the plate revolve with the magnet or the magnet with the plate the latter would be a repulsive force and is probably that the effects of which M Arago has also d scovered (8?)

126 The extraordinary circumstance accom

then the electrical currents which cause the

fluencing magnets And new modes of cutting the plate may be devised which shall almost entirely destroy its power Thus if a copper plate (81) be cut through at about a fifth or

An elementary result of this kind was obtained by using two pieces of thick copper

iment repeated, no sensible effect could be produced

128 A section of this kind could not interfere much with the induction of magnetism, supposed to be of the nature ordinarily received by iron

129 The effect of rotation or deflection of the needle, which M Arago obtained by ordinary magnets, M Ampère succeeded in procuring by electro-magnets This is perfectly in harmony with the results relative to volta-electric and magneto-electric induction described in this paper And by using flat spirals of copper wire, through which electric currents were sent, in place of ordinary magnetic poles (111), sometimes applying a single one to one side of the rotating plate, and sometimes two to opposite sides, I obtained the induced currents of electricity from the plate itself, and could lead them away to, and ascertain their existence by, the galvanometer

130 *The cause which has now been assigned for the rotation in Arago's experiment, namely, the production of electrical currents, seems abundantly sufficient in all cases where the metals, or perhaps even other conductors, are concerned*, but with regard to such bodies as glass resins, and, above all, gases, it seems impossible that currents of electricity, capable of producing these effects, should be generated in them Yet Arago found that the effects in question were produced by these and by all bodies tried (81) Messrs Babbage and Herschel it is true, did not observe them with any substance not metallic, except carbon, in a highly conducting state (82) Mr Harris has ascertained their occurrence with wood, marble, freestone and annealed glass, but obtained no effect with sulphuric acid and saturated solution of sulphate of iron, although these are better conductors of electricity than the former substances

131 *Future investigations will no doubt explain these difficulties, and decide the point whether the retarding or dragging action spoken of is always simultaneous with electric currents*[1] The existence of the *action in metals*, only whilst the currents exist, i e, whilst motion is given (82, 88), and the explication of the repulsive action observed by M Arago (82, 125), are powerful reasons for referring it to this cause, but it may be combined with others which occasionally act alone

132 Copper, iron, tin, zinc, lead, mercury, and all the metals tried, produced electrical currents when passed between the magnetic poles the mercury was put into a glass tube for the purpose The dense carbon deposited in coal gas retorts, also produced the current but ordinary charcoal did not Neither could I obtain any sensible effects with brine, sulphuric acid, saline solutions, &c, whether rotated in basins, or inclosed in tubes and passed between the poles

133 I have never been able to produce any sensation upon the tongue by the wires connected with the conductors applied to the edges of the revolving plate (88) or slips of metal (101) Nor have I been able to heat a fine platina wire, or produce a spark, or convulse the limbs of a frog *I have failed also to produce any chemical effects by electricity thus evolved* (22, 56)

134 *As the electric current in the revolving copper plate occupies but a small space, proceeding by the poles and being discharged right and left at very small distances comparatively* (123), and as it exists in a thick mass of metal possessing almost the highest conducting power of any, and consequently offering extraordinary facility for its production and discharge, and as, notwithstanding this, considerable currents may be drawn off which can pass through narrow wires, forty, fifty, sixty, or even one hundred feet long it is evident that the current existing in the plate itself must be a very powerful one, when the rotation is rapid and the magnet strong This is also abundantly proved by the obedience and readiness *with* which a magnet ten or twelve pounds in weight follows the motion of the plate and will *strongly twist up the cord by which it is suspended*

135 Two rough *trials were made with the intention of constructing magneto-electric machines In one, a ring one inch and a half broad and twelve inches external diameter*, cut from a thick copper plate, was mounted so as to revolve between the poles of the magnet and represent a plate similar to those formerly used (101), but of interminable length, the inner and outer edges were amalgamated, and the conductors applied one to each edge, at the place of the magnetic poles The current of electricity evolved did not appear by the galvanometer to be stronger, if so strong, as that from the circular plate (88).

[1] Experiments which I have since made convince me that this particular action is always due to the electrical currents formed and they supply a test by which it may be distinguished from the action of ordinary magnetism or any other cause including those which are mechanical or irregular producing similar effects (254)

136 In the other, small thick discs of copper or other metal, half an inch in diameter, were revolved rapidly near to the poles but with the axis of rotation out of the polar axis, the electricity evolved was collected by conductors applied as before to the edges (86) Currents were procured, but of strength much inferior to that produced by the circular plate

137 The latter experiment is analogous to those made by Mr Barlow with a rotating iron shell, subject to the influence of the earth [1] The effects obtained by him have been referred by *Messrs Babbage and Herschel to the* same cause as that considered as influential in Arago's experiment [2] but it would be interesting to know how far the electric current which might be produced in the experiment would account for the deflexion of the needle The mere inversion of a copper wire six or seven times near the poles of the magnet and isochronously ly with the vibrations of the galvanometer

analogous effects obtained by Mr Christie

138 The remark which has already been *made* respecting iron (66), and the independence of the ordinary magnetical phenomena of that substance and the phenomena now described of magneto-electric induction in that and other metals, was fully confirmed by many results *of the kind detailed in this section* When an iron plate similar to the copper one formerly described (101) was passed between the magnetic poles, it gave a current of electricity like the copper plate, but decidedly of less power, and in the experiments upon the induction of electric currents (9), no difference in the kind of action between iron and other metals could be perceived The power therefore of an iron plate to drag a magnet after it, or to intercept magnetic action, should be carefully distinguished from the similar power of such metals as silver, copper, &c, &c, inasmuch as in the iron by far the greater part of the effect is due to what may be called ordinary magnetic action There can be no doubt that the cause assigned by Messrs Babbage and Herschel in explication of Arago's phenomena is the true one, when iron is the metal used

[1] *Philosophical Transactions* 1825 p 317
[2] *Ibid* 1825 p 485

139 The very feeble powers which were found by those philosophers to belong to bismuth and antimony, when moving, of affecting the suspended magnet, and which has been confirmed by Mr Harris, seem at first disproportionate to their conducting powers whether it be so or not must be decided by future experiment (73) [3] These metals are highly crystalline, and probably conduct electricity with different degrees of facility in different directions, and it is not unlikely that where a mass is made up of a number of crystals heterogeneously assoc-

ed at the confines of similar crystalline arrangements, and so be more readily and completely discharged within the mass

Royal Institution, November 1831

Note In consequence of the long period which has intervened between the reading and printing of the

SECOND SERIES

§ 5 Terrestrial Magneto electric Induction § 6 General Remarks and Illustrations of the Force and Direction of Magneto-electric Induction

THE BAKERIAN LECTURE Read January 12 1832

§ 5 *Terrestrial Magneto-electric Induction*

140 WHEN the general facts described in the former paper were discovered and the law of

effect as a magnet and to an extent that would perhaps render it available in the construction of new electrical machines The following are some of the results obtained in pursuance of this view

141 The hollow helix already described (6) was connected with a galvanometer by wires

and fixed there The combined helix and bar were held in the magnetic direction or line of dip and (the galvanometer needle be ... tionless) were then ...

... ucted As the ... turned to its first position the helix and bar were again inverted and by doing this two or three times making the inversions and vibrations to coincide the needle swung through an arc of 150° or 160°

142 When one end of the helix which may be called A, was uppermost at first (B end consequently being below) then it mattered not in which direction it proceeded during the inversion whether to the right hand or left hand or through any other course still the galvanometer needle passed in the same direction Again when B end was uppermost ... of the helix and bar ...

case

143 When the helix with its iron core in any given position was inverted the effect was as if a magnet with its marked pole downwards had been introduced from above into the inverted helix Thus if the end B were upward such a magnet introduced from above would make the marked end of the galvanometer needle pass west Or the end B being downwards and the soft iron in its place, inversion of the whole produced the same effect

144 When the soft iron bar was taken out of ...

sequence of the inductive magnetic power of the earth rendering the soft iron cylinder a ... upwards The

sion of position in the present experiment is equivalent to a change of the poles in that arrangement But the result is not less an instance of the evolution of electricity by means of the magnetism of the globe

146 The helix alone was then held permanently in the magnetic direction and the soft iron cylinder afterwards introduced the galvanometer needle was instantly deflected by withdrawing the cylinder as the needle returned and continuing the two actions simultaneously the vibrations soon extended through an arc of 180° The effect was precisely the same as that obtained by using a cylinder magnet with its marked pole downwards and the direction of motion, &c was perfectly in accord ... arrangements

soft iron cylinder produced no effect at ... needle Any inclination to the dip gave results of the same kind as those already described

but increasing in strength as the hel x approx imated to the direction of the dip

147 A cylinder magnet although t has great power of affecting the galvanometer when mov ing into or out of the hel x has no power of

ance of the magnetism in the steel magnet by the earth s inductive force upon it being thus shown to be nearly if not qu te equal in amount and rapid ty to that occurring in soft iron It is probable that in this way magneto-

due to the disturbing causes

148 These favourable results led me to hope

observed. Inverting the helix ten or twelve times and at such periods that the deflect ng forces exerted by the currents of electricity produced in it should be adde l to the momen tum of the needle (39) the latter was soon made to vibrate through an arc of 80° or 90° Here therefore currents of electricity were produced by the d rect inductive power of the earth s magnetism without the use of any fer

same helix to one or both poles of any power ful magnet (50)

earth The plate so often referred to (85) was therefore fixed so as to rotate in a horizontal plane The magnetic curves of the earth (114 *note*) i e the d p passes through this plane at angles of about 70° which it was expected would be an approximation to perpendicular-ity quite enough to allow of magneto-electric induction suffic ently powerful to produce a current of electricity

the centre as the d rection of the rotation of the plate was one way or the other One of

the plate there was a distinct effect at the gal

which the latter passed soon extended to half a circle

152 When the plate revolved *screw-fashion*

of a magnet was placed beneath the revolving plate (99)

153 When the plate was in the magnet c

plate was a maximum

154 It is a striking thing to observe the re-volving copper plate become thus a *new elec-trical machine* and cur ous results arise on com paring it wit the common machine In the one the plate is of the best non-conducting substance that can be applied in the other it is the most perfect conductor in the one insu-

lation is essential, in the other, it is fatal. In comparison of the quantities of electricity produced, the metal machine does not at all fall below the glass one, for it can produce a constant current capable of deflecting the galvanometer needle, whereas the latter cannot It is quite true that the force of the current thus evolved has not as yet been increased so as to render it available in any of our ordinary applications of this power, but there appears every reasonable expectation that this may hereafter be effected and probably by several arrangements Weak as the current may seem to be, it is as strong as, if not stronger than, any thermo-electric current, for it can pass fluids (23), agitate the animal system, and in the case of an electro-magnet has produced sparks (32).

155 A disc of copper, one-fifth of an inch thick and only one inch and a half in diameter, was amalgamated at the edge a square piece of sheet lead (copper would have been better) of equal thickness had a circular hole cut in it, into which the disc loosely fitted a little mercury completed the metallic communication of the disc and its surrounding ring the latter was attached to one of the galvanometer wires, and the other wire dipped into a little metallic cup containing mercury, fixed upon the top of the copper axis of the small disc Upon rotating the disc in a horizontal plane, the galvanometer needle could be affected, although the earth was the only magnet employed and the radius of the disc but three-quarters of an inch, in which space only the current was excited

156 On putting the pole of a magnet under the revolving disc, the galvanometer needle could be permanently deflected

157 On using copper wires one-sixth of an inch in thickness instead of the smaller wires (86) hitherto constantly employed, far more powerful effects were obtained Perhaps if the galvanometer had consisted of fewer turns of thick wire instead of many convolutions of thinner, more striking effects would have been produced

158. One form of apparatus which I purpose having arranged, is to have several discs superposed, the discs are to be metallically connected, alternately at the edges and at the centres, by means of mercury, and are then to be revolved alternately in opposite directions, i e, the first, third, fifth, &c, to the right hand, and the second, fourth, sixth, &c, to the left hand, the whole being placed so that the discs are perpendicular to the dip, or intersect most directly the magnetic curves of powerful magnets The electricity will be from the cer the circumference in one set of discs, and the circumference to the centre in the each side of them thus the action of the will conjoin to produce one combined and powerful current

159 I have rather, however, been desir discovering new facts and new relation pendent on magneto-electric induction, th exalting the force of those already obt being assured that the latter would find full development hereafter

160 I referred in my former paper t probable influence of terrestrial magneto tric induction (137) in producing, either gether or in part, the phenomena observ Messrs Christie and Barlow,[1] whilst revo ferruginous bodies, and especially thos served by the latter when rapidly rotatu iron shell, which were by that philosoph ferred to a change in the ordinary dispo of the magnetism of the ball I suggested that the rotation of a copper globe would ably insulate the effects due to electric rents from those due to mere derangeme magnetism, and throw light upon the tru ture of the phenomena

161. Upon considering the law alread ferred to (114), it appeared impossible th metallic globe could revolve under natura cumstances, without having electric cur produced within it, circulating round th volving globe in a plane at right angles to plane of revolution, provided its axis of tion did not coincide with the dip, and it peared that the current would be most po ful when the axis of revolution was perpe ular to the dip of the needle for then all t parts of the ball below a plane passing thro its centre and perpendicular to the dip, w in moving cut the magnetic curves in on rection, whilst all those parts above that p would intersect them in the other direct currents therefore would exist in these mo parts, proceeding from one pole of rotatio the other, but the currents above would b the reverse direction to those below, and in junction with them would produce a contin circulation of electricity

162 As the electric currents are nowhere terrupted in the ball, powerful effects were pected, and I endeavoured to obtain them w simple apparatus The ball I used was of br

[1] Christie Phil Trans 1825, pp 58, 347, Barlow Phil. Trans., 1825 p 317.

or sometimes, to render it more steady, supported by its wire in a notched piece of wood, and motion again given by the hand The ball gave no signs of magnetism when at rest.

163 A compound magnetic needle was used

a compound arrangement was obtained, perfectly

dip, and then rotating the ball, the needle was

westward or towards the ball Upon placing the ball to the east of the needles, still the needle was deflected in the same way, i e, when the ball revolved from east over to west, the marked pole went eastward (or towards the ball); when the rotation was in the opposite direction, the marked pole went westward

dle was influenced solely by currents of electricity existing in the brass globe.

166 If the upper part of the revolving ball be considered as a wire moving from east to

the copper plate, electricity of one kind might be collected at its equator, and of the other kind at its poles

168. A current in the ball, such as that de-

way when above or below the ball, for then

needle, instead of passing eastward, went westward, and when revolved from west over to

PLATE III

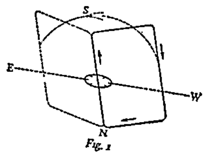


Fig. 1

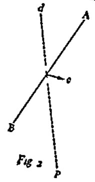
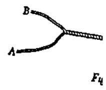
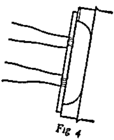


Fig 2



Fig


Fig 4

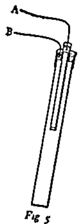


Fig 5

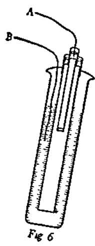
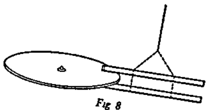


Fig 6



Fig 7


Fig 8

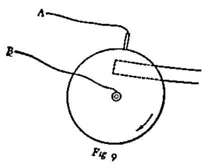


Fig 9

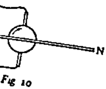


Fig 10

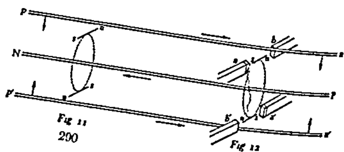


Fig 11

Fig 12

170 These results, in conjunction with the general law before stated (114), suggested an experiment of extreme simplicity, which yet, on trial, was found to answer perfectly. The exclusion of all extraneous circumstances and complexity of arrangement, and the distinct character of the indications afforded, render this single experiment an epitome of nearly all [illegible]

[illegible] of the terminations of the galvanometer wire, and the other end to the other termination; thus it formed an endless continuation of the [illegible]

[illegible] lower part, and the galvanometer attached to it, remained steady (Pl III, *Fig 1*). Upon moving this loop over the galvanometer from [illegible]

[illegible] brations of the needle (39), the latter soon swung through 90° or more.

172 The relation of the current of electricity produced in the wire, to its motion, may be understood by supposing the convolutions at the [illegible]

[illegible] pole of the magnetic needle went west; the electric current was therefore from north to [illegible]

[illegible] electricity was therefore the reverse of the former.

173. When the rectangle was arranged in a plane east and west, and the magnetic needle made parallel to it, either by the torsion of its *suspension thread or the action of a magnet*, still the general effects were the same. On moving the upper part of the rectangle from north to south, the marked pole of the needle went north; when the wire was moved in the opposite direction, the marked pole went south The same effect took place when the motion of the [illegible]

[illegible] tating ball (164).

174. In these experiments it is not necessary to move the galvanometer or needle from its first position It is quite sufficient if the wire of the rectangle is distorted where it leaves the [illegible]

[illegible] arranged *below* the galvanometer, *but so as to* be carried across the dip It affected the instrument as before, and in the same direction; i.e., when carried from west to east under the instrument, the marked end of the needle went west, as before This should, of course, be the case; for when the wire is cutting the magnetic dip in a certain direction, an electric current also in a certain direction should be induced in it.

[illegible] tached to it, both these being retained in a plane perpendicular to the dip—then, however B A with its attached arrow is moved up*on d p as an axis, if it afterwards proceed in* the direction of the arrow, a current of electricity will move along it from B towards A.

177. When the moving part of the wire was carried up or down parallel to the dip, no effect [illegible]

178 When the wire was bent into other forms and moved, equally strong effects were ob[illegible]

[illegible] combined to affect the galvanometer: but all the results were reducible to those above described.

179. The longer the extent of the moving wire, and the greater the space through which it moves, the greater is the effect upon the galvanometer.

180 The facility with which electric currents are produced in metals when moving under the influence of magnets suggests that henceforth precautions should always be taken, in [illegible]

nary to the mind, that scarcely any piece of metal can be moved in contact with others, [illegible]

[illegible]

understood

181 Upon considering the effects of terres- [illegible]

[illegible]

infinitely greater in force, may be produced by [illegible]

same direction be connected with the first by wires, it cannot discharge the current of the first because it has an equal tendency to have

the motion communicated to it from the earth [illegible]

ative electricity would be collected at the equator, and positive electricity at both poles (222) But without the conductors or something equivalent to them, it is evident these currents could not exist, as they could not be discharged

183 I did not think it impossible that some natural difference might occur between bodies, relative to the intensity of the current produced or tending to be produced in them by magneto-electric induction, which might be [illegible]

stances but between the metals themselves in their power of receiving motion from or giving it to a magnet in trials by revolution (130) I therefore took two wires each one hundred and twenty feet long, one of iron and the other of copper These were connected with each other at their ends, and then extended in the direction of the magnetic meridian so as to form two nearly parallel lines, nowhere in con [illegible]

President of the Society, I obtained the permission of His Majesty to make experiments at the lake in the gardens of Kensington Palace, for the purpose of comparing in a similar manner, water and metal The basin of this lake is artificial, the water is supplied by the Chelsea Company, no springs run into it and it presented what I required, namely, a uniform mass of still pure water, with banks ranging nearly from east to west, and from north to south

185 Two perfectly clean bright copper plates, each exposing four square feet of surface were soldered to the extremities of a copper wire the plates were immersed in the water, north and south of each other, the wire which connected them being arranged upon the grass of the bank The plates were about four hundred [illegible]

than the one sought for A little difference in temperature, a minute portion of the nitrate of mercury used to amalgamate the wires entering into the water employed to reduce the two cups of mercury to the same temperature, was sufficient to produce currents of electric-

interfering causes were guarded against, no effect was obtained, and it appeared that even such dissimilar substances as water and copper, when cutting the magnetic curves of the earth with equal velocity, perfectly neutralized each other's action

187 Mr Fox of Falmouth has obtained some highly important results respecting the electricity of metalliferous veins in the mines of Cornwall, which have been published in the *Philosophical Transactions* [1] I have examined the paper with a view to ascertain whether any of the effects were probably referable to magneto-electric induction but, though unable to form a very strong opinion, believe they are not When parallel veins running east and west were compared, the general tendency of the electricity *in the wires* was from north to south, when the comparison was made between parts towards the surface and at some depth, the current of electricity in the wires was from above downwards If there should be any natural difference in the force of the electric cur-

masses acted upon, then the wires and veins

stance acted upon produces increase of intensity, I hoped to obtain effects from extensive moving masses of water, though quiescent water gave none I made experiments therefore (by favour) at Waterloo Bridge, extending a copper wire nine hundred and sixty feet in length upon the parapet of the bridge, and

[1] 1830 p. 399

dropping from its extremities other wires with extensive plates of metal attached to them to complete contact with the water Thus the wire and the water made one conducting circuit, and as the water ebbed or flowed with the tide, I hoped to obtain currents analogous to those of the brass ball (161)

189 I constantly obtained deflections at the galvanometer, but they were very irregular, and were, in succession, referred to other causes than that sought for The different condition of the water as to purity on the two sides of the river, the difference in temperature, slight differences in the plates, in the solder used in the more or less perfect contact made by twisting or otherwise, all produced effects in turn and though I experimented on the water passing through the middle arches only, used platina plates instead of copper and took every other precaution, I could not after three days obtain any satisfactory results

190 Theoretically, it seems a necessary consequence, that where water is flowing, there

a circuit of conducting matter, one part of

ments are very limited in their extent, and as such fluids do yield the current by artificial magnets (23) (for transference of the current

* Theoretically even a ship or a boat when passing

two places equidistant from each other and from the poles of the magnet but these helices were purposely arranged so as to be in contrary directions, and therefore send contrary currents through the galvanometer coils K and L

209 On making and breaking contact between the soft iron bar and the poles of the magnet, the galvanometer was strongly affected, on detaching the zinc it was still more strongly affected in the same direction On taking all the precautions before alluded to (207), with others, it was abundantly proved that the current induced by the magnet in copper was far more powerful than in zinc

210 The copper was then compared in a similar manner with *tin*, *lead* and *iron*, and surpassed them all, even more than it did zinc The zinc was then compared experimentally with the tin, lead, and iron, and found to produce a more powerful current than any of them Iron in the same manner proved superior to tin and lead Tin came next, and lead the last

211 Thus the order of these metals is copper, zinc, iron, tin, and lead It is exactly their order with respect to conducting power for electricity, and, with the exception of iron is the order presented by the magneto-rotation experiments of Messrs Babbage, Herschel, Harris, &c The iron has additional power in the latter kind of experiments, because of its ordinary magnetic relations, and its place relative *to magneto-electric action of the kind now* under investigation cannot be ascertained by such trials In the manner above described it may be correctly ascertained [1]

212 It must still be observed that in these experiments the whole effect between different metals is not obtained, for of the thirty-four feet of wire included in each circuit, eighteen feet are copper in both, being the wire of the galvanometer coils, and as the whole circuit is concerned in the resulting force of the current, this circumstance must tend to diminish the difference which would appear between the metals if the circuits were of the same substances throughout In the present case the difference obtained is probably not more than a half of that which would be given if the whole of each circuit were of one metal

213 These results tend to prove that the currents produced by magneto-electric induction in bodies is proportional to their conducting power That they are *exactly* proportional to and altogether dependent upon the conducting power, is, I think, proved by the perfect neutrality displayed when two metals or other substances, as acid, water, &c &c (201, 186), are opposed to each other in their action The feeble current which tends to be produced in the worse conductor, has its transmission favoured in the better conductor, and the stronger current which tends to form in the latter has its intensity diminished by the obstruction of the former and the forces of generation and *obstruction are so perfectly balanced as to neu*tralize each other exactly Now as the obstruction is inversely as the conducting power, the *tendency to generate a current must be direct*ly as that power to produce this perfect equilibrium

214 The cause of the equality of action under the various circumstances described, where great extent of wire (183) or wire and water (184) were connected together, which yet produced such different effects upon the magnet, is now evident and simple

215 The effects of a rotating substance upon a needle or magnet ought, where ordinary magnetism has no influence to be directly as the conducting power of the substance and I venture now to predict that such will be found to *be the case, and that in all those instances* where non-conductors have been supposed to exhibit this peculiar influence, the motion has been due to some interfering cause of an ordinary kind as mechanical communication of motion through the parts of the apparatus or otherwise (as in the case Mr *Harris has pointed out*)[2] or else to ordinary magnetic attractions To distinguish the effects of the latter from those of the induced electric currents, I have been able to devise a most perfect test, which shall be almost immediately described (243)

216. There is every reason to believe that the magnet or magnetic needle will become an excellent measurer of the conducting power of substances rotated near it for I have found by careful experiment, that when a constant current of electricity was sent successively through a series of wires of copper, platina, zinc, silver, lead, and tin, drawn to the same diameter, the deflection of the needle was exactly equal by them all It must be remembered that when

[1] Mr Christie, who being appointed reporter upon this paper had it in his hands before it was compl[illegible] felt the difficulty (202) and to [illegible] made experiments [illegible] larg[illegible]

[2] *Philosophical Transactions* 1831, p 68

bodies are rotated in a horizontal plane the magnetism of the earth is active upon them As the effect is general to the whole of the plate, it may not interfere in these cases but in some experiments and calculations may be of im portant consequence

217 Another point which I endeavoured to ascertain was whether it was essential or not

is true has been proved already in several of the experiments on terrestrial magneto-electric induction Thus the electricity evolved from

netic force could not but be the same during the whole experiments

218 To prove the point with an ordinary

brought in contact with the circumference and the central part of the copper plate The gal vanometer needle moved as in former cases and the *direction* of motion was the *same* as that which would have resulted if the copper only had revolved and the magnet been fixed Neither was there any apparent difference in the quantity of deflection Hence rotating the magnet causes no difference in the results for a rotatory and a stationary magnet produce

and prevented from touching the magnet any where by interposed paper The arrangement was then floated in a narrow jar of mercury so that the lower edge of the copper cyl nder touched the fluid metal one wire of the galva nometer dipped into this mercury and the other into a little cavity in the centre of the end of the copper cap Upon rotating the magnet and its attached cylinder abundance of electricity

220 That the metal of the magnet itself might be substituted for the moving cylinder, disc or wire seemed an inevitable consequence and yet one which would exhib t the effects of magneto-electric induction in a striking form A cylinder magnet had therefore a little hole made in the centre of each end to receive a drop of mercury and was then floated pole upwards in the same metal contained in a narrow jar One wire from the galvanometer d pped into *the mercury of the jar and the other into the* drop contained in the hole at the upper extrem ity of the axis The magnet was then revolved

reached about half way up the magnet but when its quantity was increased until within one-eighth of an inch of the top or diminished until equally near the bottom still the same ef

mass

2?3 When the galvanometer was very sensi ble the mere spinning of the magnet in the air,

whilst one of the galvanometer wires touched the extremity, and the other the equatorial parts, was sufficient to evolve a current of electricity *and deflect the needle*

224 Experiments were then made with a similar magnet, for the purpose of ascertaining whether any return of the electric current could occur at the central or axial parts, they having *the same angular velocity of rotation as the* other parts (259) the belief being that it could not

225 A cylinder magnet, seven inches in length, and three quarters of an inch in diameter, had *a hole pierced in the direction of its* axis from one extremity, a quarter of an inch in diameter, and three inches deep A copper cylinder, surrounded by paper and amalgamated at both extremities was introduced so *as to be in metallic contact at the bottom of* the hole, by a little mercury with the middle of the magnet, insulated at the sides by the paper, and projecting about a quarter of an inch above the end of the steel A quill was put *over the copper rod*, which reached to the paper, and formed a cup to receive mercury for the completion of the circuit A high paper edge was also raised round that end of the magnet and mercury put within it, which however had no metallic connexion with that *in the* quill except through the magnet itself and the copper rod (*Pl III, Fig 5*) The wires A and B from the galvanometer were dipped into these two portions of mercury any current through them could, therefore, only pass down the magnet towards its equatorial parts, and then *up the copper rod, or vice versa*

226 When thus arranged and rotated screw fashion, the marked end of the galvanometer needle went west, indicating that there was a current through the instrument from A to B *and consequently from* B *through the magnet* and copper rod to A (*Fig 5*)

227 The magnet was then put into a jar of mercury (Pl III, *Fig 6*) as before (219), the wire A left in contact with the copper axis, but the wire B dipped in the mercury of the jar, and therefore in metallic communication with *the equatorial parts of the magnet instead of* its polar extremity On revolving the magnet screw fashion, the galvanometer needle was deflected in the same direction as before, but far more powerfully Yet it is evident that the *parts of the magnet from the equator to the* pole were out of the electric circuit

228 *Then the wire A was connected with* the mercury on the extremity of the magnet, the wire B still remaining in contact with that in the jar (Pl III, *Fig 7*), so that the copper axis was altogether out of the circuit The magnet *was again revolved screw fashion, and again* caused the same deflection of the needle, the current being as strong as it was in the last trial (227), and much stronger than at first (226)

229 Hence it is evident that there is no dis*charge of the current at the centre of the mag*net, for the current, now freely evolved is up through the magnet, but in the first experiment (226) it was down In fact, at that time it was only the part of the moving metal equal *to a little disc extending from the end of the* wire B in the mercury to the wire A that was efficient, i e moving with a different angular velocity to the rest of the circuit (258), and for that portion the direction of the current is con*sistent with the other results*

230 In the two after experiments, the *lateral* parts of the magnet or of the copper rod are those which move relative to the other parts of the circuit, i e, the galvanometer wires and *being more extensive, intersecting more curves*, or moving with more velocity, produce the greater effect For the discal part, the direction of the induced electric current is the same in all, namely, from the circumference towards the centre

231 The law under which the induced electric current excited in bodies moving relatively to magnets, is made dependent on the intersection of the magnetic curves by the metal (114) being thus rendered more precise and definite *(217, 220, 224), seem now even to apply to the* cause in the first section of the former paper (26) and by rendering a perfect reason *for the* effects produced, take away any for supposing that peculiar condition, which I ventured to *call the electro-tonic state* (60).

232 When an electrical current is passed through a wire, that wire is *surrounded at every* part by magnetic curves, diminishing in intensity according to their distance from *the* wire, and which in idea may be likened to rings situated in planes perpendicular to the wire or *rather to the electric current within it* These curves, although different in form, are perfectly analogous to those existing *between two* contrary magnetic poles opposed to each other, and when a second wire, parallel to that whi[ch] carries the current, is made to approach t[he] latter (18), it passes through magnetic curv[es] *exactly of the same kind as those it would in*tersect when carried between opposite mag

other direction

233 If the wire N P (Pl III, *Fig 11*) have

direction of the principal current (19) The same effect would take place if by inverting the direction of motion of the wire in passing between either set of poles (*Fig 12*) it were

234 But if the current of electricity were made to cease for a while, and magnetic poles were used instead to give direction to the needles and make them take the same position as when under the influence of the current, then they must be arranged as at Pl III, *Fig 12* the marked and unmarked poles *a b* above the wire being in opposite directions to those *a b* below In such a position therefore the magnetic curves between the poles *a b* and *a' b'* have the same general direction with the corresponding parts of the ring magnetic curve surround

curves, similar in direction to that figured and consequently similar in direction to those between the poles *a b* of the magnets (*Fig 12*) and it will intersect these current curves in the same manner as it would the magnet curves if it passed from above between the poles downwards Now such an intersection would with the magnets induce an electric current in the wire from *p* to *n* (114) and therefore as the curves are alike in arrangement the same effect ought to result from the intersection of the magnetic curves dependent on the current in the wire N P, and such is the case for on ap-

When the second wire is retained at rest in the vicinity of the principal wire no current is induced through it, for it is intersecting no

then an electric current sent through the former In such cases the magnetic curves themselves must be considered as moving (if I may use the expression) across the wire under in

from the wire outwards and consequently being in the same relation to the fixed wire under induction as if *it* had moved in the opposite direction across them, or towards the wire carrying the current Hence the first current induced in such cases was in the contrary direction to the principal current (17, 235) On breaking the battery contact the magnetic curves (which are mere expressions for arranged magnetic

induced current to the first

239 When in experiments with ordinary magnets the latter in place of being moved past the wires were actually made near them (27 36), then a similar progressive development of the magnetic curves may be considered as having taken place, producing the effects which would have occurred by motion of the wires in one direction the destruction of the magnetic power corresponds to the motion of the wire in the opposite direction

240 If, instead of intersecting the magnetic

the magnetic curves, then it ought to have continuous electric currents induced within it and if a line joining the wire with the centre of the plate were perpendicular to both then the induced current ought to be, according to the law (114), directly across the plate from one

side to the other, and at right angles to the direction of the inducing current

241 A single metallic wire one-twentieth of an inch in diameter had an electric current passed through it, and a small copper disc one inch and a half in diameter revolved near to and under, but not in actual contact with it (Pl III, *Fig 10*) Collectors were then applied at the opposite edges of the disc, and wires from them connected with the galvanometer As the disc revolved in one direction, the needle was deflected on one side, and when the direction of revolution was reversed, the needle was inclined on the other side, in accordance with the results anticipated

242 Thus the reasons which induce me to suppose a particular state in the wire (60) have disappeared, and though it *still seems* to me unlikely that a wire at rest in the neighbourhood of another carrying a powerful electric current is entirely indifferent to it, yet I am not aware of any distinct *facts* which authorize the conclusion that it is in a particular state

243 In considering the nature of the cause *assigned in these papers to account for the mutual* influence of magnets and moving metals (120), and comparing it with that heretofore admitted, namely, the induction of a feeble magnetism like that produced in iron, it occurred to me that a most decisive experimental test of the two views could be applied (215)

244 No other known power has like direction with that exerted between an electric current and a magnetic pole, it is tangential while all other forces, acting at a distance, are direct Hence, if a magnetic pole on one side of a revolving plate follow its course by reason of its obedience to the tangential force exerted upon it by the very current of electricity which it has itself caused, a similar pole on the opposite side of the plate should immediately set it free from *this force, for the currents which tend to* be formed by the action of the two poles are in opposite directions, or rather no current tends to be formed, or no magnetic curves are intersected (114), and therefore the magnet should remain at rest On the contrary, if the action of a north magnetic pole were to produce a southness in the nearest part of the copper plate, and a diffuse northness elsewhere (82), as is really the case with iron, then the use of another north pole on the opposite side of the same part of the plate should double the effect instead of destroying it, and double the tendency of the first magnet to move with the plate

245 A thick copper plate (85) was therefore fixed on a vertical axis, a bar magnet was suspended by a plaited silk cord, so that its marked pole hung over the edge of the plate, and a sheet of paper being interposed, the plate was revolved, immediately the magnetic pole obeyed its motion and passed off in the same direction A second magnet of equal size and strength was then attached to the first, so that its marked pole should hang *beneath* the edge of the copper plate in a corresponding position to that above, and at an equal distance (Pl III, *Fig 8*) Then a paper sheath or screen being interposed as before, and the plate revolved, the poles were found entirely indifferent to its motion although either of them alone would have followed the course of rotation

246 On turning one magnet round, *so that opposite* poles were on each side of the plate, then the mutual action of the poles and the moving metal was a maximum

247 On suspending one magnet so that its axis was level with the plate, and either pole opposite its edge, the revolution of the plate caused no motion of the magnet The electrical *currents dependent upon induction* would now tend to be produced in a vertical direction across the thickness of the plate, but could not be so discharged, or at least only to so slight a degree as to leave all effects insensible, but ordinary magnetic induction, or that on an iron plate, would be equally if not more powerfully developed in such a position (251)

248 Then, with regard to the production of electricity in these cases whenever motion was communicated by the plate to the magnets, currents existed, when it was not communicated, they ceased A marked pole of a large bar magnet was put under the edge of the plate collectors (86) applied at the axis and edge of the plate as on former occasions (Pl III, *Fig 9*), and these connected with the galvanometer *when the plate was revolved*, abundance of electricity passed to the instrument The unmarked pole of a similar magnet was then put over the place of the former pole, so that contrary poles were above and below, on revolving the plate, the electricity was more powerful than before The latter magnet was then turned end for end, so that marked poles were both above and below the plate, and then, upon revolving it, scarcely any electricity was procured By adjusting the distance of the poles so as to correspond with their relative force, they at last were brought so perfectly to neutralize each other's inductive action upon the

plate that no electricity could be obtained with the most rapid motion

249 I now proceeded to compare the effect of similar and dissimilar poles upon iron and copper, adopting for the purpose Mr Sturgeon's very useful form of Arago's experiment This consists in a circular plate of metal supported in a vertical plane by a horizontal axis,

and edges of these plates and then the number of vibrations, required to reduce the vi

in iron

250 I had two such plates mounted, one of copper, one of iron The copper plate alone gave sixty vibrations, in the average of several experiments, before the arc of vibration was reduced from one constant mark to another On placing opposite magnetic poles near to, and on each side of, the same place, the vibrations were reduced to fifteen On putting similar poles on each side of it, they rose to fifty,

ed a certain quantity On presenting a magnetic pole to the edge of the plate (247), the vibrations were diminished to eleven and when the

marked pole of the second bar was put on the opposite side of the plate at the same distance (250), the vibrations were reduced to two But when the second pole was an unmarked one, yet occupying exactly the same position, the vibrations rose to twenty two By removing the stronger of these two opposite poles a little way from the plate, the vibrations increased to thirty-one, or nearly the original number But

[1] *Edin. Phil Journal* 1825 p 124.

on removing it *altogether*, they fell to between five and six

253 Nothing can be more clear, therefore, than that with iron, and bodies admitting of ordinary magnetic induction, *opposite* poles on opposite sides of the edge of the plate neutralize each other's effect, whilst *similar* poles exalt

causes not anticipated and consequently not

but none in three

lastly th
the r

256 although it will require further research, and probably close investigation, both experimental and mathematical, before the exact mode of action between a magnet and metal moving relatively to each other is ascertained, yet many of the results appear sufficiently clear and simple to allow of expression in a somewhat general manner If a terminated wire move so as to cut a magnetic curve, a power is called into action which tends to urge an electric current through it but this current cannot be brought into existence unless provision be made at the ends of the wire for its discharge and renewal

257 If a second wire move in the same direction as the first, the same power is exerted upon it, and it is therefore unable to alter the condition of the first for there appear to be no natural differences among substances when connected in a series, by which, when moving under the same circumstances relative to the magnet, one tends to produce a more powerful electric current in the whole circuit than another (201, 214)

258 But if the second wire move with a different velocity, or in some other direction, then variations in the force exerted take place and if connected at their extremities, an electric current passes through them

259 Taking, then, a mass of metal or an endless wire, and referring to the pole of the magnet as a centre of action (which though perhaps not strictly correct may be allowed for facility of expression, at present), if all parts move in the same direction and with the same angular velocity, and through magnetic curves of constant intensity, then no electric currents are produced This point is easily observed with masses subject to the earth's magnetism, and may be proved with regard to small magnets by rotating them, and leaving the metallic arrangements stationary, no current is produced

260 If one part of the wire or metal cut the magnetic curves, whilst the other is stationary, then currents are produced All the results obtained with the galvanometer are more or less of this nature, the galvanometer extremity being the fixed part Even those with the wire, galvanometer, and earth (170), may be considered so without any error in the result

261 If the motion of the metal be in the *same direction, but the angular velocity* of its parts relative to the pole of the magnet different, then currents are produced This is the case in Arago s experiment, and also in the wire subject to the earth's induction (172) when it was moved from west to east

262 If the magnet moves not directly to or from the arrangement, but laterally, then the case is similar to the last

263 If different parts move in opposite directions across the magnetic curves, then the effect is a maximum for equal velocities

264 All these in fact are variations of one simple condition, namely, *that all parts of the mass shall not move in the same direction across the curves, and with the same angular velocity* But they are forms of expression which, being retained in the mind, I have found useful when comparing the consistency of particular phenomena with general results.

Royal Institution, December 21, 1831

THIRD SERIES

§ 7. Identity of Electricities Derived from Different Sources § 8 Relation by Measure of Common and Voltaic Electricity

READ JANUARY 10TH and 17TH, 1833

§ 7 Identity of Electricities Derived from Different Sources

265 THE progress of the electrical researches which I have had the honour to present to the Royal Society, brought me to a point at which it was essential for the further prosecution of my inquiries that no doubt should remain of the identity or distinction of electricities excited by different means It is perfectly true that Cavendish,[1] Wollaston,[2] Colladon,[3] and others, have in succession removed some of the greatest objections to the acknowledgement of the identity of common, animal and voltaic

[1] *Phil Trans* 1776 p 196
[2] *Ibid* 1801 p 434
[3] *Annales de Chimie*, 1826 p 62 &c

electricity, and I believe that most philosophers consider these electricities as really the same But on the other hand it is also true that the accuracy of Wollaston's experiments has been denied,[1] and also that one of them, which really is no proper proof of chemical decomposition by common electricity (309, 327), has been that selected by several experimenters as the test of chemical action (336, 346) It is a fact, too, that many philosophers are still drawing distinctions between the electricities from different sources or at least doubting whether their identity is proved Sir Humphry Davy, *for instance*, in his paper on the Torpedo,[2] thought it probable that animal electricity would be found of a peculiar kind and referring to it, to common electricity, voltaic electricity and magnetism, has said, "Distinctions might be established in pursuing the various modifications or properties of electricity in these different forms, &c" Indeed I need only refer to the last volume of the *Philosophical Transactions* to show that the question is by no means considered as settled [3]

[1] *Phil Trans* 1832 p 282 note

266 Notwithstanding therefore, the general impression of the identity of electricities it is evident that the proofs have not been sufficiently clear and distinct to obtain the assent of all those who were competent to consider the subject, and the question seemed to me very much in the condition of that which Sir H Davy solved so beautifully—namely, whether voltaic electricity in all cases merely eliminated, or did not in some actually produce, the acid and alkali found after its action upon water The same necessity that urged him to decide the doubtful point, which interfered with the ex-

[illegible]

they are identical, and I hope the experiments which I have to offer and the proofs flowing from them, will be found worthy the attention of the Royal Society

267 The various phenomena exhibited by electricity may, for the purposes of comparison, be arranged under two heads namely, those connected with electricity of tension, and those belonging to electricity in motion This distinction is taken at present not as philosophical, but merely as convenient The effect of electricity of tension, at rest, is either attraction or repulsion at sensible distances The effects of electricity in motion or electrical currents may be considered as 1st, evolution of heat, 2nd, magnetism 3rd chemical decom-

[illegible]

I. *Voltaic Electricity*

[illegible]

or more of air intervenes

269 That ordinary electricity is discharged by points with facility through air that it is readily transmitted through highly rarefied air, and also through heated air, as for instance a flame, is due to its high tension I sought, therefore, for similar effects in the discharge of voltaic electricity, using as a test of the passage of the electricity either the galvanometer

PLATE IV

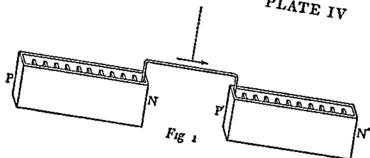


Fig 1

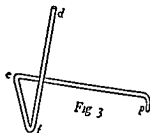


Fig 3

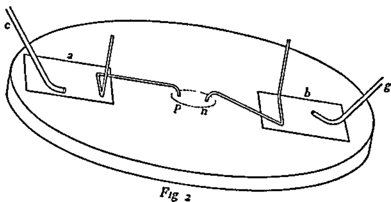


Fig 2

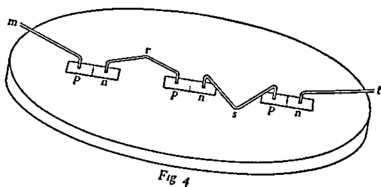


Fig 4

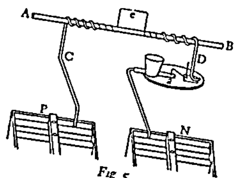


Fig 5

or chemical action produced by the arrangement hereafter to be described (312, 316)

270 The voltaic battery I had at my disposal consisted of 140 pairs of plates four inches square, with double coppers It was insulated throughout, and diverged a gold leaf electrom

obtain no indications of a current, either by magnetic or chemical action In this, however, was found no point of discordance between voltaic and common electricity for when a

er magnetic or chemical action This was not because common electricity could not produce

stead of difference between voltaic and com-

ends of which are brought very close to each other at *e*, but without touching the copper wire C was connected with the positive pole of

only two troughs, or twenty pairs of plates, were used

272 Whilst in the state described, no decomposition took place at the point *a*, but when the side of a spirit-lamp flame was applied to the two platina extremities at *e* so as to make them bright red hot, decomposition occurred, iodine soon appeared at the point *a*, and the transference of electricity through the heated air was established On raising the temperature of the points *e* by a blowpipe, the discharge was rendered still more free, and decomposition took place instantly On removing the source of heat, the current immediately ceased On putting the ends of the wires very close by the side of and parallel to each other, but not touch-

tained

273 On removing the decomposing apparatus and interposing a galvanometer instead,

through heated air, but the instrument used was not so sensible under the circumstances as chemical action

274 These effects, not hitherto known or expected under this form, are only cases of the discharge which takes place through air between the charcoal terminations of the poles of a powerful battery, when they are gradually separated after contact Then the passage is through heated air exactly as with common electricity, and Sir H Davy has recorded that with the original battery of the Royal Institution this discharge passed through a space of

275 The instantaneous charge of a Leyden battery by the poles of a voltaic apparatus is

tensity

276 *In Motion* i *Evolution of Heat* The evolution of heat in wires and fluids by the voltaic

[1] *Elements of Chemical Philosophy* p 153.
[2] *Ibid.*, p 154.

no effect can be more distinctive of an electrical current

278 III *Chemical Decomposition* The chemical powers of the voltaic current, and their subjection to *certain laws*, are also perfectly well known

279. IV *Physiological Effects* The power of the voltaic current, when strong, to shock and convulse the whole animal system, and when weak to affect the tongue and the eyes, is very characteristic

280 V *Spark* The brilliant star of light produced by the discharge of a voltaic battery is known to all as the most beautiful light that man can produce by art

281 That these effects may be almost infinitely varied, some being exalted whilst others are diminished, is universally acknowledged and yet without any doubt of the identity of character of the voltaic currents thus made to differ in their effect The beautiful explication of these variations afforded by Cavendish's theory of quantity and intensity requires no support at present, as it is not supposed to be doubted

282 In consequence of the comparisons that will hereafter arise between wires carrying voltaic and ordinary electricities, and also because of certain views of the condition of a wire or any other conducting substance connecting the poles of a voltaic apparatus, it will be necessary to give some definite expression of what is called the voltaic current, in contradistinction to any supposed peculiar state of arrangement, not progressive, which the wire or the electricity within it may be supposed to assume If two voltaic troughs P N, P′ N′, Pl IV, *Fig 1*, be symmetrically arranged and insulated, and the ends N P′ connected by a wire, over which a magnetic needle is suspended, the wire will exert no effect over the needle but immediately that the ends P N′ are connected by another wire, the needle will be deflected, and will remain so as long as the circuit is complete Now if the troughs merely act by causing a peculiar arrangement in the wire either of its particles or its electricity, that arrangement constituting its electrical and magnetic state, then the wire N P′ should be in a similar state of arrangement *before* P and N′ were connected, to what it is afterwards, and should have deflected the needle, although less powerfully, perhaps to one-half the extent which would result when the communication is complete throughout But if the magnetic effects depend upon a current, then it is evident why they could not be produced in *any* degree before the circuit was complete, because prior to that no current could exist

283 By *current*, I mean anything progressive, whether it be a fluid of electricity, or two fluids moving in opposite directions, or merely vibrations, or, speaking still more generally, progressive forces. By *arrangement*, I understand a local adjustment of particles, or fluids, or forces, not progressive Many other reasons might be urged in support of the view of a *current* rather than an *arrangement*, but I am anxious to avoid stating unnecessarily what will occur to others at the moment

II *Ordinary Electricity*

284 By ordinary electricity I understand that which can be obtained from the common machine, or from the atmosphere, or by pressure, or cleavage of crystals, or by a multitude of other operations, its distinctive character being that of great intensity, and the exertion of attractive and repulsive powers, not merely at sensible but at considerable distances

285 *Tension* The attractions and repulsions at sensible distances, caused by ordinary electricity, are well known to be so powerful in certain cases, as to surpass, almost infinitely, the similar phenomena produced by electricity otherwise excited But still those attractions and repulsions are exactly of the same nature as those already referred to under the head *Tension, Voltaic electricity* (268), and the difference in degree between them is not greater than often occurs between cases of ordinary electricity only I think it will be unnecessary to enter minutely into the proofs of the identity of this character in the two instances They are abundant are generally admitted as good, and lie upon the surface of the subject and whenever in other parts of the comparison I am about to draw, a similar case occurs, I shall content myself with a mere announcement of the similarity, enlarging only upon those parts where the great question of distinction or identity still exists

286. The discharge of common electricity through heated air is a well known fact The parallel case of voltaic electricity has already been described (272, &c)

287 *In Motion* I *Evolution of Heat* The heating power of common electricity, when passed through wires or other substances, is perfectly well known The accordance between it and voltaic electricity is in this respect complete Mr Harris has constructed and describ-

common electricity is readily shown and to which I shall have occasion to refer for experimental proof in a future part of this paper (344)

288 ii *Magnetism* Voltaic electricity has most extraordinary and exalted magnetic powers If common electricity be identical with it,

tricity has been found deficient so that sometimes its power has been denied altogether, and at other times distinctions have been hypothetically assumed for the purpose of avoiding the difficulty[2]

ences in 1826[3] describes experiments in which,

fully confirm those by M Colladon and I should have had no occasion to describe them, but that they are essential as proofs of the ac

290 The plate electrical machine I have used is fifty inches in diameter, it has two sets of rubbers its prime conductor consists of two

[1] *Philosophical Transactions* 1827 p 18 *Edinburgh Transactions* 1831 Harris on a New Electrometer &c &c

[2] Demonferrand s *Manuel d electricité dynamique* p 121

[3] *Annales de Chimie* XXXIII p 62

brass cylinders connected by a third the whole length being twelve feet and the surface in contact with air about 1422 square inches

may easily be drawn from the conductors Each turn of the machine when worked moderately, occupies about 9/10ths of a second

291 The electric battery consisted of fifteen equal jars They are coated eight inches upwards from the bottom and are twenty three inches in circumference, so that each contains one hundred and eighty four square inches of glass coated on both sides this is independent of the bottoms which are of thicker glass and contain each about fifty square inches

fectual in its office as to carry off instantaneously electricity of the feeblest tension even that of a single voltaic trough and was essential to many of the experiments

with a frame of wirework having numerous sharp points projecting from it When this

the galvanometer is very liable to have its mag

make common electricity assume more of the characters and power of voltaic electricity, than it is usually supposed to have

296 The coating and armour of the galvanometer were first connected with the discharging train (292), the end B (87) of the galvanometer wire was connected with the outside coating of the battery, and then both these with the discharging train, the end A of the galvanometer wire was connected with a discharging rod by a wet thread four feet long, and finally, when the battery (291) had been positively charged by about forty turns of the machine, it was discharged by the rod and the thread through the galvanometer The needle immediately moved

297 During the time that the needle completed its vibration in the first direction and returned, the machine was worked, and the battery recharged and when the needle in vibrating resumed its first direction, the discharge was again made through the galvanometer By repeating this action a few times, the vibrations soon extended to above 40° on each side of the line of rest

298 This effect could be obtained at pleasure Nor was it varied, apparently, either in direction or degree by using a short thick string, or even four short thick strings in place of the long fine thread With a more delicate galvanometer, an excellent swing of the needle could be obtained by one discharge of the battery

299 On reversing the galvanometer communications so as to pass the discharge through from B to A, the needle was equally well deflected, but in the opposite direction

300 The deflections were in the same direction as if a voltaic current had been passed through the galvanometer, i e, the positively charged surface of the electric battery coincided with the positive end of the voltaic apparatus (268), and the negative surface of the former with the negative end of the latter

301 The battery was then thrown out of use, and the communications so arranged that the current could be passed from the prime conductor, by the discharging rod held against it, through the wet string through the galvanometer coil, and into the discharging train (292), by which it was finally dispersed This current could be stopped at any moment, by removing the discharging rod, and either stopping the machine or connecting the prime conductor by another rod with the discharging train; and could be as instantly renewed The needle was so adjusted, that whilst vibrating in moderate and small arcs, it required time equal to twenty five beats of a watch to pass in one direction through the arc, and of course an equal time to pass in the other direction

302 Thus arranged, and the needle being stationary, the current, direct from the machine, was sent through the galvanometer for twenty five beats, then interrupted for other twenty-five beats, renewed for twenty five beats more again interrupted for an equal time, and so on continually The needle soon began to vibrate visibly, and after several alternations of this kind, the vibration increased to 40° or more

303 On changing the direction of the current through the galvanometer, the direction of the deflection of the needle was also changed. In all cases the motion of the needle was in direction the same as that caused either by the use of the electric battery or a voltaic trough (300)

304 I now rejected the wet string, and substituted a copper wire, so that the electricity of the machine passed at once into wires communicating directly with the discharging train, the galvanometer coil being one of the wires used for the discharge The effects were exactly those obtained above (302)

305 Instead of passing the electricity through the system, by bringing the discharging rod at the end of it into contact with the conductor, four points were fixed on to the rod, when the current was to pass, they were held about twelve inches from the conductor, and when it was not to pass, they were turned away Then operating as before (302), except with this variation, the needle was soon powerfully deflected, and in perfect consistency with the former results Points afforded the means by which Colladon, in all cases, made his discharges

306 Finally, I passed the electricity first through an exhausted receiver, so as to make it there resemble the aurora borealis and then through the galvanometer to the earth and it was found still effective in deflecting the needle, and apparently with the same force as before

307 From all these experiments, it appears that a current of common electricity, whether transmitted through water or metal, or rarefied air, or by means of points in common air, is still able to deflect the needle the only requisite being, apparently, to allow time for its action that it is, in fact, just as magnetic in every respect as a voltaic current, and that in this character therefore no distinction exists.

308 Imperfect conductors, as water, brine, acids, &c , &c , will be found far more convenient for exhibiting these effects than other modes of discharge, as by points or balls, for the former convert at once the charge of a powerful battery into a feeble spark discharge, or rather continuous current, and involve little or no risk of deranging the magnetism of the needles (294)

309 iii *Chemical Decomposition* The chemical action of voltaic electricity is characteristic of that agent, but not more characteristic than are the *laws* under which the bodies evolved by decomposition arrange themselves at the poles Dr Wollaston showed[1] that common electricity resembled it in these effects, and "that they are both *essentially the same*", but he mingled with his proofs an experiment having a resemblance, and nothing more, to a case of voltaic decomposition, which however he himself partly distinguished and this has been more frequently referred to by some, on the one hand, to prove the occurrence of electro-chemical decomposition, like that of the pile, and by others to throw doubt upon the whole paper, than the more numerous and decisive experiments which he has detailed

310 I take the liberty of describing briefly my results, and of thus adding my testimony to that of Dr Wollaston on the identity of voltaic and common electricity as to chemical action, not only that I may facilitate the repetition of the experiments, but also lead to some new consequences respecting electro-chemical decomposition (376, 377)

311 I first repeated Wollaston's fourth experiment[2] in which the ends of coated silver

little copper was precipitated, and no sensible trace of silver from the other pole appeared in the solution

312 A much more convenient and effectual arrangement for chemical decompositions by common electricity, is the following Upon a glass plate, Pl IV, *Fig 2*, placed over, but raised above a piece of white paper, so that shadows may not interfere, put two pieces of

[1] *Philosophical Transactions* 1801 pp. 427, 434
[2] *Ibid.*, 1801 p 429

tinfoil *a*, *b*, connect one of these by an insulated

two pieces of fine platina wire, bent as in Pl IV, *Fig 3*, so that the part *d*, *f* shall be nearly upright, whilst the whole is resting on the three

nute as possible, can be obtained at pleasure, and the connexion can be broken or renewed in a moment, and the substances acted upon examined with the utmost facility

313 A coarse line was made on the glass with solution of sulphate of copper, and the terminations *p* and *n* put into it, the foil *a* was connected with the positive conductor of the machine by wire and wet string, so that no sparks passed twenty turns of the machine caused the precipitation of so much copper on the end *n*, that it looked like copper wire no apparent change took place at *p*

314 A mixture of equal parts of muriatic acid and water was rendered deep blue by sulphate of indigo, and a large drop put on the

utmost degree A piece of paper moistened in the solution of iodide of potassium and starch,

than the galvanometer (273) Such cases occur when the bodies traversed by the current are bad conductors, or when the quantity of electricity evolved or transmitted in a given time is very small

317. A piece of litmus paper moistened in solution of common salt or sulphate of soda, was quickly reddened at *p* A similar piece moistened *in muriatic acid was very soon bleached* at *p* No effects of a similar kind took place at *n*.

318. A piece of turmeric paper moistened in solution of sulphate of soda was reddened at *n* by two or three turns of the machine, and in twenty or thirty turns plenty of alkali was there evolved On turning the paper round, so *that the spot came under p, and then working* the machine, the alkali soon disappeared, the place became yellow, and a brown alkaline spot *appeared in the new part under n*

319 On combining a piece of litmus with a piece of turmeric paper, wetting both with solution of sulphate of soda, and putting the paper on the glass, so that *p* was on the litmus and *n* on the turmeric, a very few turns of the machine sufficed to show the evolution of acid at the former and alkali at the latter, exactly in *the manner effected by a volta-electric current*

320 All these decompositions took place equally well, whether the electricity passed from the machine to the foil *a, through water,* or through wire only, by *contact* with the conductor, or by *sparks there*, provided the sparks were not so large as to cause the electricity to pass in sparks from *p* to *n*, or towards *n* and I have seen *no reason to believe that in cases of* true electro-chemical decomposition by the machine, the electricity passed in sparks from the conductor, *or at any part of the current, is able* to do more, because of its tension, than that *which is made to pass merely as a regular current*

321 Finally, the experiment was extended *into the following form, supplying in this case* the fullest analogy between common and voltaic electricity Three compound pieces of litmus and turmeric paper (319) were moistened in solution of sulphate of soda, and arranged *on a plate of glass with platina wires, as in Pl* IV, *Fig* 4 The wire *m* was connected with the prime conductor of the machine, the wire *t* with the discharging train, and the wires *r* and *s* entered into the course of the electrical current by means of the *pieces of moistened paper*, they were so bent as to rest each on three points, *n, r, p, n, s, p*, the points *r* and *s* being *supported by the glass, and the others by the* papers, the three terminations *p, p, p* rested on the litmus, and the other three *n, n, n* on the turmeric paper On working the machine for a short time only, acid was evolved at *all the poles or terminations p, p, p,* by which the electricity entered the solution, and alkali at the other poles *n, n, n*, by which the electricity *left the solution*

322 In all experiments of electro-chemical decomposition by the common machine and *moistened papers (316), it is necessary to be* aware of and to avoid the following important source of error. If a spark passes over moistened litmus and turmeric paper, the litmus paper (provided it be delicate and not too alkaline), *is reddened by it, and if several sparks are* passed, it becomes powerfully reddened If the electricity pass a little way from the wire over *the surface of the moistened paper, before it* finds mass and moisture enough to conduct it, then the reddening extends as far as the ramifications If similar ramifications occur at the termination *n*, on the turmeric paper, they *prevent* the occurrence of the *red spot due to* the alkali, which would otherwise collect there sparks or ramifications from the points *n will also redden litmus paper* If *paper moistened* by a solution of iodide of potassium (which is an admirably delicate test of electro-chemical action), be exposed to the sparks or ramifications, or even a feeble stream of electricity *through the air from either the point p or n*, iodine will be immediately evolved

323 These effects must not be confounded with those due to the true electro-chemical powers of common electricity, and must be *carefully avoided when the latter* ... served No spark ... in any ... intensit ... be indu ... and the ... conduct ... effect ref ... (322) ensues

324. The effect itself *is due to the formation* of nitric acid by the combination of the oxygen and nitrogen of the air, and *is, in fact, only a delicate repetition of* Cavendish's beautiful experiment The acid so formed, though small in quantity, is in a high state of concentration as to water, and produces the consequent effects of reddening the litmus paper, or *preventing the exhibition of alkali on the turmeric paper;* or, by acting on the iodide of potassium, evolving iodine

325 By moistening a very small slip of litmus paper in solution of caustic potassa [1] and then passing the electric spark over its length in the air I gradually neutralized the alkali and ultimately rendered the paper red on drying it I found that *nitrate of potassa had resulted* from the operation and that the paper had become touch paper

326 Either litmus paper or white paper, moistened in a strong solution of iodide of potassium offers therefore a very simple beauti ful and ready means of illustrating Cavend sh s experiment of the formation of nitric acid from the atmosphere

327 I have already had occasion to refer to an experiment (265 309) made by Dr Wollas

fine wires with glass or other insulating substances and then removing only so much matter as to expose the point or a section of the wires and by pass ng electric ty through two such wires the guarded points of which were immersed in water Wollaston found that the *water could be decomposed even by the current* from the machine without sparks and that

that the effect is different from that of the voltaic p le inasmuch as both oxygen and hydrogen are evolved from *each* pole he calls it a very close *imitation* of the galvanic phenomena but adds that 'in fact the resemblance is not complete and does not trust to it to establish the principles correctly laid down in his paper

328 This experiment is neitl er more nor less than a repetition in a refined manner of that made by Dr Pearson in 1797 [2] and previously by MM Paets Van Troostwyk and Deiman in 1789 or earlier That the experiment should

water is decomposed at both poles independently of each other and the oxygen and hydrogen evolved at the wires are the elements of the water existing the instant before in those places That the poles or rather points have no mutual decomposing dependence may be

tirely the wire used for the other communica

portionate to the intensity but to the quantity of electricity passed (320) Of this I sl all be able to offer some proofs in a future part of this paper (375 3/7) But in the experiment under consideration this is not the case If with a constant pair of points the electricity be passed from the machine in sparks a certain proportion of gas is evolved but if the sparks be rendered shorter less gas is evolved and if *no sparks be passed there is scarcely a* sens ble portion of gases set free On substituting solu

seemed more copious than the othe and on turning the apparatus round still the same side in relation to the machine gave tl e largest

[1] *Potassa caustica* or caust c potash now known as potassium hydroxide —Ed

[2] *Nicholson s Journal* 4to Vol 1 pp 241 299 349

electro-chemical action, because I shall have occasion to refer to it in cases of supposed chemical action by magneto-electric and other electric currents (336, 346) and elsewhere But, independent of it, there cannot be now a doubt that Dr Wollaston was right in his general conclusion, and that voltaic and common electricity have powers of chemical decomposition, alike in their nature, and governed by the same law of arrangement.

332 iv *Physiological Effects* The power of *the common electric current to shock and convulse the animal system, and when weak to affect the tongue and the eyes, may be considered* as the same with the similar power of voltaic electricity, account being taken of the intensity of the one electricity and duration of the other When a wet thread was interposed in the course of the current of common electricity from the battery (291) charged by eight or ten[1] revolutions of the machine in good action (290), and the discharge made by platina spatulas through the tongue or the gums, the effect upon the tongue and eyes was exactly that of a momentary *feeble voltaic circuit*

333 v. *Spark* The beautiful flash of light *attending the discharge of common electricity is* well known It rivals in brilliancy, if it does not even very much surpass, the light from the discharge of voltaic electricity, but it endures for an instant only, and is attended by a sharp noise like that of a small explosion Still no difficulty can arise in recognising it to be the same spark as that from the voltaic battery, especially under certain circumstances The eye cannot distinguish the difference between a voltaic and a common electricity spark, *if they be taken between amalgamated surfaces of metal*, at intervals only, and through the same distance of air

334 When the Leyden battery (291) was discharged through a wet string placed in some part of the circuit away from the place where the spark was to pass, the spark was yellowish, flamy, having a duration sensibly longer than if the water had not been interposed, was about three-fourths of an inch in length, was accompanied by little or no noise, and whilst losing part of *its usual character had approximated in some* degree to the voltaic spark When the electricity retarded by water was discharged between pieces of charcoal, it was exceedingly luminous and bright upon both surfaces of the charcoal, resembling the brightness of the voltaic discharge on such surfaces When the discharge of the unretarded electricity was taken upon charcoal, it was bright upon both the surfaces (in that respect resembling the voltaic spark), but the noise was loud, sharp, and ringing

335 I have assumed, in accordance, I believe, with the opinion of every other philosopher, that atmospheric electricity is of the same nature with ordinary electricity (284), and I might therefore refer to certain published statements of chemical effects produced by the former as proofs that the latter enjoys the power *of decomposition in common with voltaic electricity* But the comparison I am drawing is far too rigorous to allow me to use these statements without being fully assured of their accuracy, yet I have no right to suppress them, because, if accurate, they establish what I am labouring to put on an undoubted foundation, and have priority to my results

336 M Bonijol of Geneva[*] is said to have constructed very delicate apparatus for the decomposition of water by common electricity By connecting an insulated lightning rod with his apparatus, the decomposition of the water *proceeded in a continuous and rapid manner even when the electricity of the atmosphere was not very powerful* The apparatus is not described, but as the diameter of the wire is mentioned as very small, it appears to have been similar in construction to that of Wollaston (327), and as that does not furnish a case of true polar electro-chemical decomposition (328), this result of M Bonijol does not prove the identity in chemical action of common and voltaic electricity

337 *At the same page of the Bibliothèque Universelle*, M Bonijol is said to have decom*posed potash, and also chloride of silver*, by putting them into very narrow tubes and pass*ing electric sparks from an ordinary machine* over them It is evident that these offer no analogy to cases of true voltaic decomposition, where the electricity only decomposes when it *is conducted* by the body acted upon, and ceases to decompose, according to its ordinary laws, when it passes in sparks These effects are prob*ably partly analogous to that which takes place with water in Pearson's or Wollaston's apparatus, and may be due to very high temperature* acting on minute portions of matter, or they may be connected with the results in air (322) As nitrogen can combine directly with oxygen under the influence of the electric spark (324), it is not impossible that it should even take it from the potassium of the potash, especially as

[1] Or even from thirty to forty

[*] *Bibliothèque Universelle*, 1830, Vol. XLV, p 213

there would be plenty of potassa in contact with the acting particles to combine with the nitric acid formed However distinct all these actions may be from true polar electro chemical

in the details that it would seem at once to prove the identity in chemical action of common and voltaic electricity but when examined considerable difficulty arises in reconciling certain of the effects with the remainder

ed with solution of sulphate of soda coloured with syrup of violets and connected by a portion of the same solution in the ordinary manner the wire in one tube was connected by a

strength or intensity of the atmospheric elec-

mon electricity is shown by several circumstances Wollaston could not effect the decom

either of water or of a neutral salt by the use of the machine I have lately tried the large machine (?90) in full action for a quarter of an hour during which time seven hundred revolutions were made without producing any sensible effects although the shocks that it would

for common electricity to have produced the effect the quantity must have been awfully great and apparently far more than could have been conducted to the earth by a gilt thread

and at the same time only have produced the usual shocks

340 Th

taic battery even when it has a tension so feeble as not to strike through the eighth of an inch of air

341 It seems just possible that the air which

the explanation seems very doubtful I charged

This battery thus arranged produced feeble de-

unlimited It gave no shocks to compare with the usual shocks of a kite-string

342 Mr Barry s experiment is a very important one to repeat and verify If confirmed it will be as far as I am aware the first record

[1] *Philosophical Transactions* 1831 p. 165

[1] *Annales de Chimie* L, p 322.
[2] *Ibid.* LI p 77

can heat a wire in the manner of ordinary electricity At the British Association of Science at Oxford, in June of the present year, I had the pleasure, in conjunction with Mr Harris, Professor Daniell, Mr Duncan, and others, of making an experiment, for which the great magnet in the museum Mr Harris's new electrometer (287), and the magneto electric coil described in my first paper (34), were put in requisition The latter had been modified in the manner I have elsewhere described,[1] so as to produce an electric spark when its contact with the magnet was made or broken The terminations of the spiral, adjusted so as to have their contact with each other broken when the spark was to pass, were connected with the wire in the electrometer, and it was found that each time the magnetic contact was made and broken, expansion of the air within the instrument occurred, indicating an increase, at the moment, of the temperature of the wire

345 ii *Magnetism* These currents were discovered by their magnetic power

346 iii *Chemical Decomposition* I have made many endeavours to effect chemical decomposition by magneto-electricity, but unavailingly In July last I received an anonymous letter (which has since been published)[2] describing a magneto-electric apparatus, by which the decomposition of water was effected As the term "guarded points" is used, I suppose the apparatus to have been Wollaston's (327 &c), in which case the results did not indicate polar electro-chemical decomposition Signor Botto has recently published certain results which he has obtained [3] but they are, as at present described, inconclusive The apparatus he used was apparently that of Dr Wollaston, which gives only fallacious indications (327 &c) [illegible]s magneto-electricity [illegible]

[illegible] already [illegible] has however, in the hands of himself[4] and M Hachette,[5] given decisive chemical results, so as to complete this link in the chain of evidence Water was decomposed by it, and the oxygen and hydrogen obtained in separate tubes according to the law governing volta-electric and machine-electric decomposition

347 iv. *Physiological Effects* A frog was convulsed in the earliest experiments on these currents (56) The sensation upon the tongue, and the flash before the eyes, which I at first obtained only in a feeble degree (56), have been since exalted by more powerful apparatus, so as to become even disagreeable

348 v *Spark* The feeble spark which I first obtained with these currents (32) [illegible] varied and streng[illegible] Antino[illegible] as to [illegible] common electric spark

IV *Thermo-electricity*

349 With regard to thermo-electricity, (that beautiful form of electricity discovered by Seebeck), the very conditions under which it is excited are such as to give no ground for expecting that it can be raised like common electricity to any high degree of tension, the effects, therefore due to that state are not to be expected The sum of evidence respecting its analogy to the electricities already described, is I believe, as follows —*Tension* The attractions and repulsions due to a certain degree of tension have not been observed *In Currents* i *Evolution of Heat* I am not aware that its power of raising temperature has been observed ii *Magnetism* It was discovered, and is best recognised, by its magnetic powers iii *Chemical Decomposition* has not been effected by it iv *Physiological Effects* Nobili has shown[6] that these currents are able to cause contractions in the limbs of a frog v *Spark* The spark has not yet been seen

350 Only those effects are weak or deficient which depend upon a certain high degree of intensity and if common electricity be reduced in that quality to a similar degree with the thermo-electricity, it can produce no effects beyond the latter

V *Animal Electricity*

351 After an examination of the experiments of Walsh,[7] Ingenhousz,[8] Cavendish,[9] Sir H Davy,[10] and Dr Davy,[11] no doubt remains on my mind as to the ident[illegible]

[illegible] proved by his brother Dr

[1] Phil Mag and Annals 1832 Vol. XI p 405
[2] Lond and Edinb Phil Mag and Journ 1832 Vol I p 161
[3] Ibid 1832 Vol I p 441
[4] Annales de Chimie LI, p 77
[5] Ibid, LI, p 72
[6] Bibliothèque Universelle XXXVII 15
[7] Philosophical Transactions 1773 p 461
[8] Ibid 1775 p 1
[9] Ibid., 1776, p 196
[10] Ibid 1829 p 15
[11] Ibid 1832 p 259

Davy the results of the latter being the reverse of those of the former At present the sum of evidence is as follows

352 *Tension* No sens ble attractions or repulsions due to tension have been observed

353 *In Motion* i *Evolution of Heat* not yet observed I have little or no doubt that Har ris s electrometer would show it (287 359)

354 ii *Magnetism* Perfectly d st nct Ac

nary and volta c electricity

355 iii *Chemical Decomposition* Also dis tinct and though Dr Davy used an apparatus of s m lar construct on with that of Dr Wol laston (327) still no error in the present case is

not on the other and when these wires were e ther steel or silver in solution of common salt gas (hydrogen?) rose from the negative wire but none from the pos t ve

356 Another reason for the decompos t on be ng electro-chemical is that a Wollaston s apparatus constructed with *wires* coated by sealing wax would most probably not have decomposed water even in ts own peculiar way unless the electric ty had risen high enough in intens ty to produce sparks in some part of the circu t whereas the torpedo was *not able to* produce sens ble sparks A third reason is that the purer the water in Wollaston s apparatus the more abundant is the decompos tion and I have found that a machine and w re points wh ch succeeded perfectly well with d st lled water failed altogether when the water was rendered a good conductor by sulphate of soda common salt or other sal ne bod es But in Dr Davy s experiments with the torpedo *strong* solut ons of salt n trate of s lver and superacetate of lead were used successfully and there is no doubt with more success than weaker ones

357 iv *Physiological Effects* These are so characterist c that by them the pecul ar pow ers of the torpedo and *gymnotus* are pr nc pal ly recogn sed

358 v *Spark* The electr c spark has not yet been obtained or at least I th nk not but perhaps I had better refer to the evidence on this po nt Humboldt speaking of results obtained by M Fahlberg of Sweden says This philos opher has seen an electr c spark as Walsh and Ingenhousz had done before him in London by

such an observat on by e ther Walsh or Ingen housz and do not know where to refer to that by M Fahlberg M Humboldt could not him

a darkened room but he does not say he saw them himself nor state who d d see them nor

tween these two cases

360 The *general conclusion* which must I think be drawn from this collect on of facts is

Philosophical Transactions 1832 p. 260

stances of *quantity* and *intensity*[1] which can at pleasure be made to change in almost any one of the kinds of electricity, as much as it does between one kind and another

Table of the Experimental Effects Common to the Electricities Derived from Different Sources[2]

	Physiological Effects	Magnetic Deflection	Magnets made	Spark	Heating Power	True chemical Action	Attraction and Repulsion	Discharge by Hot Air
1 Voltaic Electricity	×	×	×	×	×	×	×	×
2 Common Electricity	×	×	×	×	×	×	×	×
3 Magneto-electricity	×	×	×	×	×	×	×	
4 Thermo-electricity	×	×	+	+	+	+		
5 Animal electricity	×	×	×	+	+	×		

§ 8 *Relation by Measure of Common and Voltaic Electricity*[3]

361 Believing the point of identity to be satisfactorily established, I next endeavoured to obtain a common measure, or a known relation as to quantity, of the electricity excited by a machine, and that from a voltaic pile for the purpose not only of confirming their identity (378), but also of demonstrating certain general principles (366, 377, &c), and creating an extension of the means of investigating and applying the chemical powers of this wonderful and subtile agent

362 The first point to be determined was whether the same absolute quantity of ordinary electricity, sent through a galvanometer, under different circumstances, would cause the same deflection of the needle An arbitrary scale was therefore attached to the galvanometer, each division of which was equal to about 4°, and the instrument arranged as in former experiments (296) The machine (290), battery (291), and other parts of the apparatus were brought into good order, and retained for the time as nearly as possible in the same condition The experiments were alternated so as to indicate any change in the condition of the apparatus and supply the necessary corrections

363 Seven of the battery jars were removed, and eight retained for present use It was found that about forty turns would fully charge the eight jars They were then charged by thirty turns of the machine, and discharged through the galvanometer, a thick wet string, about ten inches long, being included in the circuit The needle was immediately deflected five divisions and a half, on the one side of the zero, and in vibrating passed as nearly as possible through five divisions and a half on the other side

364 The other seven jars were then added to the eight, and the whole fifteen charged by thirty turns of the machine The Henley's electrometer stood not quite half as high as before but when the discharge was made through the galvanometer, previously at rest, the needle immediately vibrated, passing exactly to the same division as in the former instance. These experiments with eight and with fifteen jars were repeated several times alternately with the same results

365 Other experiments were then made, in which all the battery was used, and its charge (being fifty turns of the machine), sent through the galvanometer but it was modified by being passed sometimes through a mere wet thread, sometimes through thirty-eight inches of thin string wetted by distilled water, and sometimes through a string of twelve times the thickness, only twelve inches in length, and soaked in dilute acid (298) With the thick string the charge passed at once with the thin string it occupied a sensible time, and with the thread it required two or three seconds before the electrometer fell entirely down The current therefore must have varied extremely in intensity in these different cases, and yet the deflection of the needle was sensibly the same in all of them If any

[1] The term *quantity* in electricity is perhaps sufficiently definite as to sense the term *intensity* is more difficult to define strictly I am using the terms in their ordinary and accepted meaning

[2] Many of the spaces in this table originally left blank may now be filled Thus with *thermo-electricity* Botto made magnets and obtained polar chemical decomposition Antinori produced the spark and if it has not been done before Mr Watkins has recently heated a wire in Harris's thermo-electrometer In respect to *animal electricity* Matteucci and Linari have obtained the spark from the torpedo and I have recently procured it from the *gymnotus* Dr Davy has observed the heating power of the current from the torpedo I have therefore filled up these spaces with crosses in a different position to the others originally in the table There remain but five spaces unmarked two under *attraction and repulsion* and three under *discharge by hot air*, and though these effects have not yet been obtained it is a necessary conclusion that they must be possible since the *spark* corresponding to them has been procured For when a discharge across cold air can occur that intensity which is the only essential additional requisite for the other effects must be present —*Dec* 13, 1838

[3] In further illustration of this subject see 855–873 in Series VII.—*Dec* 1838.

difference occurred, it was that the thin string and thread caused greatest deflection and if there is any lateral transmission, as M Colladon says, through the silk in the galvanometer coil it ought to have been so, because then the intensity is lower and the lateral transmission less

366 Hence it would appear that *if the same absolute quantity of electricity pass through the galvanometer, whatever may be its intensity, the deflecting force upon the magnetic needle is the same*

367 The battery of fifteen jars was then charged by sixty revolutions of the machine, and discharged as before through the galvanometer The deflection of the needle was now as nearly as possible to the eleventh division, but the graduation was not accurate enough

absolute quantity of electricity passed at whatever intensity that electricity may be [1]

368 Dr Ritchie has shown that in a case where the intensity of the electricity remained the same, the deflection of the magnetic needle was directly as the quantity of electricity passed through the galvanometer [2] Mr Harris has shown that the *heating* power of common electricity on metallic wires is the same for the same quantity of electricity whatever its intensity might have previously been [3]

369 The next point was to obtain a *voltaic* arrangement producing an effect equal to that just described (367) A platina and a zinc wire were passed through the same hole of a draw plate, being then one-eighteenth of an inch in diameter these were fastened to a support so that their lower ends projected were parallel, and five-sixteenths of an inch apart The upper ends were well connected with the galvanometer wires Some acid was diluted, and after various preliminary experiments that adopted as a standard which consisted of one drop strong sulphuric acid in four ounces distilled water Finally, the time was noted which the needle required in swinging either from right to left or left to right it was equal to seventeen beats of my watch the latter giving one hundred and fifty in a minute The object of these preparations was to arrange a voltaic apparatus which, by immersion in a given acid for a given time, much less than that required by the needle to

and a new part of the zinc wire having been brought into position with the platina, the comparative experiments were made

division and then returned swinging an equal distance on the other side This experiment was repeated many times, and always with the same result

372 In order to procure a reference to *chemical action*, the wires were now retained in

[1] The great and general value of the galvanometer as an actual measure of the electricity passing through

[2] *Quarterly Journal of Science* New Series Vol I p 33

[3] *Plymouth Transactions* p. 22

trical battery charged by thirty turns of the machine

373 The following arrangements and results are selected from many that were made and obtained relative to chemical action A platina wire one-twelfth of an inch in diameter, weighing two hundred and sixty grains, had the extremity rendered plain, so as to offer a definite surface equal to a circle of the same diameter as the wire, it was then connected in turn with the conductor of the machine, or with the voltaic apparatus (369), so as always to form the *positive* pole, and *at the same time retain a* perpendicular position, that it might rest, with its whole weight, upon the test paper to be employed The test paper itself was supported upon a platina spatula connected either with the discharging train (292), or with the negative wire of the voltaic apparatus, and it consisted of four thicknesses, moistened at *all* times to an equal degree in a standard solution of *hydriodate of potassa* (316)

374 When the platina wire was connected with the prime conductor of the machine, and the spatula with the discharging train, ten turns of the machine had such decomposing power as to produce a pale round spot of iodine of the diameter of the wire, twenty turns made a much darker mark, and thirty turns made a dark brown spot penetrating to the second thickness of the paper The *difference in effect* produced by two or three turns, more or less, could be distinguished with facility

375 The wire and spatula were then connected with the voltaic apparatus (369), the galvanometer being also included in the arrangement, and, a stronger acid having been prepared, *consisting* of nitric acid and water, the voltaic apparatus was immersed so far as to give a permanent deflection of the needle to the 5½ division (372), the fourfold moistened paper intervening as before [1] Then by shifting the end of the wire from place to place upon the test paper, the effect of the current for five, six, seven, or any number *of the beats of the watch* (369) was observed, and compared with that of the machine After alternating and repeating the experiments of comparison many times, it was constantly found that this standard current of voltaic electricity, continued for eight beats of the watch, was equal [illegible]
thi[illegible]

[1] [illegible] the heightened power of the voltaic battery was necessary to compensate for the bad conductor now interposed.

376 Hence it results that both in *magnetic deflection* (371) and in *chemical force*, the current of electricity of the standard voltaic battery *for eight beats of the watch was equal to* that of the machine evolved by thirty revolutions

377 It also follows that for this case of electro-chemical decomposition, and it is probable for all cases, that the *chemical power*, *like the magnetic force* (366), *is in direct proportion to the absolute quantity of electricity* which passes.

378 Hence arises still further confirmation, if any were required, *of the identity of common* and voltaic electricity, and that the differences of intensity and quantity are quite sufficient to account for what were supposed to be their distinctive qualities

379 The extension which the present investigations have enabled me to make of the facts and views constituting the theory of *electro*-chemical decomposition, will, with some other *points of electrical doctrine*, be almost immediately submitted to the Royal Society in another series of these *Researches*

Royal Institution, Dec 15, 1832

NOTE I am anxious and am permitted to add to this paper a correction of an error which I have attributed to M Ampère in the first series of these *Experimental Researches* In referring to his experiment on the induction of electrical currents (78) I have called that a disc which I should have called a circle or a ring M Ampère used a ring or a very short cylinder made of a narrow plate of copper bent into a circle and he tells me that by such an arrangement *the motion is very readily obtained* I have not doubted that M Ampère obtained the motion he described but merely mistook the kind of mobile conductor used and so far I described his *experiment* erroneously

In the same paragraph I have stated that M Ampère says the disc turned to take a position of equilibrium exactly as the spiral itself would have turned had it been free to move and farther on I have said that my results tended to invert the sense of the proposition stated by M Ampère *that a current of electricity tends to put the electricity of conductors near which it passes in motion in the same direction* M Ampère tells me in a letter which I have just received from him that he carefully avoided when describing the experiment any referen[illegible]
tion of the induce[illegible]
passe[illegible]

t[illegible]
u[illegible]
e[illegible]
a[illegible]
M[illegible]
th[illegible]
int[illegible]
ar[illegible]
the[illegible]
acc[illegible]
rou[illegible]

[1] [illegible]othèque Universelle XXI, p 48.

It was the precise statements in Demonferrand s

in error

Hence the m stake into which I unwittingly fell I am proud to correct it and do full justice to the acuteness and accuracy which as far as I can understand the subjects M Ampère carr es into all the branches of philosophy which he in vestigates

FOURTH SERIES

§ 9 On a New Law of Electric Conduction § 10 On Conducting Power Generally

Received April 24, Read May 23, 1833

§ 9 *On a New Law of Electric Conduction*[1]

380 It was during the progress of investiga tions relating to electro chemical decomposi

erto recognised and though they prevented me from obtaining the condition I sought for they afforded abundant compensation for the momentary disappointment by the new and important interest which they gave to an extensive part of electrical science

381 I was working with ice and the solids resulting from the freezing of solutions, ar ranged either as barriers across a substance to be decomposed or as the actual poles of a vol

erful voltaic battery, the transmission of elec tricity was prevented and all decomposition ceased

382 At first the experiments were made with common ice during the cold freezing weather of the latter end of January 1833 but the re

were easily connected when required with a voltaic pile Then distilled water, previously

tremities of the voltaic apparatus a galvanometer being at the same time included in the circuit

[1] In reference to this law see further cons derations at 910 1358 1705 —*Dec* 1838

in the water or ice, and as the vessel was four-eighths of an inch in width, the average thickness of the intervening ice was only a quarter *of an inch, whilst the surface* of contact with it at both poles was nearly fourteen square inches After the water was frozen, the vessel was still retained *in the frigorific mixture, whilst* contact between the tin and platina respectively was made with the extremities of a well charged *voltaic battery, consisting of twenty pair of* four inch plates, each with double coppers Not the slightest deflection of the galvanometer needle occurred

385 On taking the frozen arrangement out of the cold mixture, and applying warmth to the bottom of the tin case, so as to melt part of the ice, the connexion with the battery being in the mean time retained, the needle did not at first move and it was only when the thawing process had extended so far as to liquefy *part of the ice touching the platina pole, that* conduction took place, but then it occurred effectually, and the galvanometer needle was *permanently deflected nearly 70°*

386 In another experiment, a platina spatula, five inches in length and seven-eighths of an inch in width, had four inches fixed in the ice, and the latter was only three-sixteenths of an inch thick between one metallic surface and the other, yet this arrangement insulated as perfectly as the former

387 Upon pouring a little water in at the top of this vessel on the ice, still the arrangement did not conduct, yet fluid water was evidently *there This result was the consequence of the* cold metals having frozen the water where they touched it, and thus insulating the fluid part; and it well illustrates the non-conducting power of ice, by showing how thin a film could prevent the transmission of the battery current Upon thawing parts of this thin film, at *both* metals, conduction occurred

388. *Upon warming the tin case and removing* the piece of ice, it was found [illegible] having slipped one [illegible] had [illegible] [illegible] ...ing the [illegible] interfering ice in this [illegible], no sensible portion of electricity had passed

389 *These experiments were repeated many* times with the same results At last a battery of fifteen troughs, or one hundred and fifty *pairs of four-inch plates*, powerfully charged, was used yet even here no sensible quantity of electricity passed the thin barrier of ice

390 It seemed at first as if occasional departures from these effects occurred but they could always be traced to some interfering circumstances The water should in every instance be well frozen, for though it is not necessary that the ice should reach from pole to pole, *since a barrier of it about one pole would be* quite sufficient to prevent conduction, yet if part remain fluid, the mere necessary exposure *of the apparatus to the air or the approxima*tion of the hands, is sufficient to produce, at the *upper surface* of the water and ice, a film of *fluid, extending from the platina to the tin* and then conduction occurs Again, if the corks used to block the platina in its place are damp or wet within, it is *necessary that the cold be* sufficiently well applied to freeze the water in *them*, or else when the surfaces of their contact with the tin become slightly warm by handling, that part will conduct, and the interior being ready to conduct *also, the current* will pass The water should be pure, not only that unembarrassed results may be obtained but *also that, as the freezing proceeds,* a minute portion of concentrated saline solution may not be formed which remaining fluid and being interposed in the ice, or passing into cracks resulting from contraction, may exhibit conducting powers independent of the *ice itself*

391 On one occasion I was surprised to find that after thawing much of the ice the conducting power *had not been restored, but I found* that a cork which held *the* wire just where it joined the platina, dipped so far into the ice, *that with the ice itself it protected* the platina from contact with the melted part long after that contact was expected

392 This insulating power of ice is not effective with electricity of exalted intensity *On* touching a diverged *gold leaf electrometer* with a wire connected with the platina, whilst the tin case was touched by the hand or another *wire, the electrometer was instantly* discharged (419)

393 But though electricity of an intensity so low that *it cannot* diverge the electrometer, can still pass (though in very limited quantities (419)) through ice *the comparative* relation of water and ice to the electricity of the voltaic apparatus is not less extraordinary *on that account, or less important* in its consequences

394 As it did not seem likely that this *law of the assumption of conducting power during liquefaction, and loss of it during congelation,* would be *peculiar to water, I immediately* pro-

common temperatures, but readily fusible, and of such composition as, for other reasons connected with electro-chemical action, led to the conclusion that they would be able when fused to replace water as conductors A voltaic battery of two troughs, or twenty pairs of four-inch plates (384), was used as the source of electricity, and a galvanometer introduced into the circuit to indicate the presence or absence of a current

395 On f s ng a l ttle chlor de of lead by a

powerful action, the galvanometer was most violently affected, and the chloride rapidly decomposed On removing the lamp, the instant the chloride solidified all current and consequent effects ceased,

stantly passed

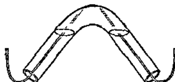
396 On fusing the chloride, with one wire

so hot as to be able to admit or allow of contact with the liquid matter, that conduction took place, and then it was very powerful

397 When chloride of silver and chlorate of potassa were experimented with, in a similar manner, exactly the same results occurred

398 Whenever the current passed in these cases, there was decomposition of the substances but the electro chemical part of this subject I purpose connecting with more gen-

the other, dipped into them In this way chloride of sodium, sulphate of soda, protoxide of lead, mixed carbonates of potash and soda, &c, &c, exhibited exactly the same phenomena as those already described whilst liquid they conducted and were decomposed whilst solid, though very hot, they insulated the battery current even when four troughs were used



400 Occasionally the substances were contained in small bent tubes of green glass, and when fused, the platina poles introduced, one

dides of potassium and lead gave iodine at the

401 A fourth arrangement was used for sub-

a small ring, in the manner described by Berzelius for blowpipe experiments a little of the

First, *water*

protoxide of lead,

strontium, calcium, magnesium, manganese,

zinc, copper (proto-), lead, tin (proto-), antimony, silver

Iodides of pot
dide of tin
potassium,
nide of pot

Salts Chlorate of potassa, nitrates of pot
sa, soda
ver
of m
copp
lime
and
of tin, chromate of potassa, bichromate of potassa, chromate of lead, acetate of potassa

Sulphurets[1] Sulphuret of antimony, sulphuret of potassium made by reducing sulphate of potassa by hydrogen, ordinary sulphuret of potassa

of
liq
ing
exal
ate
glass, it has
not cond

softening was probably due to the elevat

Sulphur
aci
car
coc
line
and
liqu
dicated by the galvanometer, nor were they decomposed

407 Some of the above substances are sufficiently remarkable as exceptions to

408 Boracic acid was raised to the possible temperature by an oxy-hydrogen (401), yet it gained no conducting power

prop
crea
erful
on th
on th ... show the assumption of conducting power upon fusion and the accompany

containing that proport

part of water, more or less than necessary, would, upon cooling the whole cause a portion of uncongealable liquid to separate and that remaining in the interstices of the solid mass and moistening the planes of division would prevent the correct observation of the phenomena due to entire solidification and subsequent liquefaction

410

iodides, salts, &c, &c, it is given in a much higher degree I have not had time to measure the conducting power in these cases, but it is apparently some hundred times that of pure water The increased conducting power known to be given to water by the addition of salts,

water

[1] *Sulphuret* a sulphide The *uret* ending was formerly used for all binary compounds —ED

See a doubt on this point at 1356 —*Dec* 1833.

411 Whether the conducting power of these liquefied bodies is a consequence of their decomposition or not (413), or whether the two act ons of conduction and decomposit on are essent ally connected or not would introduce no difference affecting the probable accuracy of the preceding statement

412 This *general assumption of conducting power* by bodies as soon as they pass from the solid to the liquid state offers a new and extra ordinary character the existence of which as far as I know has not before been suspected and t seems importantly connected with some propert es and relations of the particles of matter which I may now briefly point out

such as contain elements known to arrange themselves at the opposite poles and were also such as could be *decomposed* by the electrical current When conduction took place decom pos tion occurred when decomposition ceased conduction ceased also and it becomes a fair and an important question Whether the con duction itself may not wherever the law holds good be a consequence not merely of the cap ab l ty but of the act of decomposit on? And that question may be accompanied by another namely Whether solidification does not prevent conduction merely by chaining the particles to their places under the influence of ag gregat on and preventing their final separation in the manner necessary for decompos tion?

414 But on the other hand there is one

relation however of conduction and decompo s tion in those bodies governed by the general law which it is the object of this paper to establish can only be satisfactorily made out from a far more extensive series of observations than those I have yet been able to supply [1]

416 The relation under this *law* of the con ducting power for electricity to that for heat is very remarkable and seems to imply a natural dependence of the two As the solid becomes a fluid it loses almost entirely the pow er of conduction for heat but gains in a high

patible still they are most strongly contrasted one being lost as the other is gained We may hope perhaps hereafter to understand the

cerned

417 The assumpt on of conducting power

cyanides fluorides certain vitreous mixtures &c &c may be submitted to the action of the voltaic battery under new circumstances and indeed I have already been able with ten pairs of plates to decompose common salt chloride of magnesium borax &c &c and to obtain sodium magnes um boron &c in their separate states

general stock of knowledge relating to this point of electrical science

See 6 9 &c &c —*Dec* 1838

[1] In reference to this § refer to 983 in series VIII and the results connected with it.—*Dec.* 1838.

connected with a delicate gold leaf electrometer, and also with the platina inclosed in the ice (383), whilst the tin case was connected

tin case was five-eighths of an inch in width and as, after the experiment, the platina plate was found very nearly in the middle of the ice, the average thickness of the latter had been five-sixteenths of an inch, and the extent of surface of contact with tin and platina fourteen square inches (384) Yet, under these circumstances, it was but just able to conduct the small quantity of electricity which this machine could evolve (371), even when of a tension competent to open the leaves two inches, no wonder, therefore, that it could not conduct any sensible portion of the electricity of the troughs (384), which, though almost infinitely surpassing that of the machine in quantity, had a tension so low as not to be sensible to an electrometer

was introduced into the course of the electricity from the machine (419), the gold leaves could be opened, but not more than half an inch, the thinness of the ice favouring the conduction of the electricity, and permitting the same quantity to pass in the same time, though of a much lower tension

421 Iodide of potassium which had been fused and cooled was introduced into the course of the electricity from the machine There were

compared to the facility with which enormous quantities at very low tensions are transmitted by it when in the fluid state

432 In order to confirm these results by others, obtained from the voltaic apparatus a battery of one hundred and fifty plates four

four tenths of an inch of air, and the gold leaf electrometer before used could be opened nearly a quarter of an inch

424 The ice vessel employed (420) was half an inch in width, as the extent of contact of the ice with the tin and platina was nearly fourteen square inches, the whole was equivalent to a plate of ice having a surface of seven square inches, of perfect contact at each side and only one-fourth of an inch thick It was retained in a freezing mixture during the experiment

425 The order of arrangement in the course of the electric current was as follows The positive pole of the battery was connected by a wire with the platina plate in the ice, the plate was in contact with the ice, the ice with the tin

or decomposing end being supported on paper moistened with solution of iodide of potassium (316) the paper was laid flat on a platina spatula connected with the negative end of the battery All that part of the arrangement between the ice vessel and the decomposing wire point including both these, was insulated, so that no electricity might pass through the latter which had not traversed the former also

426 Under these circumstances, it was found that a pale brown spot of iodine was slowly formed under the decomposing platina point

that notwithstanding the enormous quantity of electricity which the battery could furnish,

an inch or more (419, 420)

427 The decomposing wire and solution of iodide of potassium were then removed, and replaced by a very delicate galvanometer (205); it was so nearly astatic, that it vibrated to and

from about sixty-three beats of a watch giving one hundred and fifty beats in a minute The same feebleness of current as before was still indicated, the galvanometer needle was deflected, but it required to break and make contact three or four times (297), before the effect was decided

428 The galvanometer being removed, two

battery, so far as the ice would let it pass, was free to go through the tongue Whilst standing on the stone floor, there was shock, &c, but when insulated, I could feel no sensation I think a frog would have been scarcely, if at all, affected

429 The ice was now removed, and experiments made with other solid bodies, for which purpose they were placed under the end of the decomposing wire instead of the solution of iodide of potassium (425) For instance, a piece of dry iodide of potassium was placed on the

use of the electrical machine (421) When the

action on the galvanometer Fused and cooled chloride of lead produced the same effect The conducting power of these bodies, *when fluid*, is very great (395, 402)

431 These effects produced by using the common machine and the voltaic battery, agree therefore with each other, and with the law

well known

tallic bodies, as observed and described by Sir Humphry Davy [1]

433 The substance presenting this effect is sulphuret of silver It was made by fusing a mixture of precipitated silver and sublimed sulphur, removing the film of silver by a file

process The surface of the sulphuret being again removed by a file or knife, it was considered quite free from uncombined silver

434 When a piece of this sulphuret, half an inch in thickness, was put between surfaces of platina, terminating the poles of a voltaic battery of twenty pairs of four inch plates, a gal-

gers, the conducting power increased as the whole became warm On applying a lamp under the sulphuret between the poles, the conducting power rose rapidly with the heat, and at last the galvanometer needle jumped into a fixed position, and the sulphuret was found

vanometer

435 Occasionally, when the contact of the sulphuret with the platina poles was good, the battery freshly charged, and the commencing temperature not too low, the mere current of electricity from the battery was sufficient to raise the temperature of the sulphuret, and then, without any application of extraneous

was conveniently avoided by inserting the ends of two pieces of platina wire into the opposite extremities of a portion of sulphuret fused in a glass tube, and placing this arrangement between the poles of the battery

437. The hot sulphuret of silver conducts sufficiently well to give a bright spark with charcoal, &c, &c, in the manner of a metal

438 The native grey sulphuret of silver, and the ruby silver ore, both presented the same phenomena The native malleable sulphuret of silver presented precisely the same appearances as the artificial sulphuret.

439 There is no other body with which I am acquainted, that, like sulphuret of silver, can compare with metals in conducting power for electricity of low tension when hot, but which, unlike them, during cooling, loses in power, whilst they, on the contrary, gain Probably, however, many others may, when sought for, be found [1]

440 The proto-sulphuret of iron, the native per-sulphuret of iron, arsenical sulphuret of iron, native yellow sulphuret of copper and iron, grey artificial sulphuret of copper, artificial sulphuret of bismuth, and artificial grey sulphuret of tin, all conduct the voltaic battery current when cold, more or less, some giving sparks like the metals, others not being sufficient for that high effect They did not seem to conduct better when heated, than before, but I had not time to enter accurately into the investigation of this point Almost all of them became much heated by the transmission of the current, and present some very interesting phenomena in that respect The sulphuret of antimony does not conduct the same current sensibly either hot or cold, but is amongst those bodies acquiring conducting power when fused (402) The sulphuret of silver and perhaps some others decompose whilst in the solid state but the phenomena of this decomposition will be reserved *for its proper place in the next series* of these *Researches*

441. Notwithstanding the extreme dissimilarity between sulphuret of silver and gases or vapours, I cannot help suspecting the action of heat upon them to be the same, bringing them all into the same class as conductors of electricity, although with those great differences in degree, which are found to exist under common circumstances When gases are heated, they increase in conducting power, both for common and voltaic electricity (271), and it is probable that if we could compress and condense them at the same time, we should still further increase their conducting power Cagniard de la Tour has shown that a substance, for instance water, may be so expanded by heat whilst in the liquid state, or condensed whilst in the vaporous state, that the two states shall coincide at one point, and the transition from one to the other be so gradual that no line of demarcation can be pointed out,[2] that, in fact, the two states shall become one, which one state presents us at different times with differences in degree as to certain properties and relations, and which differences are, under ordinary circumstances, so great as to be equivalent to two different states

442 I cannot but suppose at present that at that point where the liquid and the gaseous state coincide, the conducting properties are the same for both but that they diminish as the expansion of the matter into a rarer form takes place by the removal of the necessary pressure still, however, retaining, as might be expected, the capability of having what feeble conducting power remains, increased by the action of heat

443 I venture to give the following summary of the conditions of electric conduction in bodies, not however without fearing that I may have omitted some important points [3]

444 All bodies conduct electricity in the same manner, from metals to lac and gases, but in very different degrees

445 Conducting power is in some bodies powerfully increased by heat, and in others diminished, yet without our perceiving any accompanying essential electrical difference, either in the bodies or in the changes occasioned by the electricity conducted

446 A numerous class of bodies, insulating electricity of low intensity when solid, conduct it very freely when fluid, and are then decomposed by it

447 But there are many fluid bodies which do not sensibly conduct electricity of this low intensity, there are some which conduct it and are not decomposed, nor is fluidity essential to decomposition [4]

448. There is but one body yet discovered[5] which, insulating a voltaic current when solid,

[1] See now on this subject, 1340 1341 —*Dec* 1838

[2] *Annales de Chimie* XXI pp 127, 178

[3] See now in relation to this subject 1320–1312 —*Dec* 1838

[4] See the next series of these *Experimental Researches*

[5] It is just possible that this case may by more delicate experiment hereafter disappear (See now, 1340, 1341, in relation to this note —*Dec.* 1838.)

and conducting it when fluid, is not decomposed in the latter case (414)

449 There is no strict electrical distinction of conduction which can, as yet, be drawn between bodies supposed to be elementary and those known to be compounds

Royal Institution, April 15, 1833

FIFTH SERIES

§ 11. *On Electro-chemical Decomposition* ¶ i. *New Conditions of Electro-chemical Decomposition* ¶ ii *Influence of Water in Electro-chemical Decomposition* ¶ iii *Theory of Electro chemical Decomposition*

Received June 18, Read June 20, 1833

§ 11 *On Electro-Chemical Decomposition*[1]

450 I have in a recent series of these *Researches* (265) proved (to my own satisfaction, at least), the identity of electricities derived from different sources, and have especially dwelt upon the proofs of the sameness of those obtained by the use of the common electrical machine and the voltaic battery

451 The great distinction of the electricities obtained from these two sources is the very high tension to which the small quantity obtained by aid of the machine may be raised, and the enormous quantity (371, 376) in which that of comparatively low tension, supplied by the voltaic battery, may be procured but as their actions, whether magnetical, chemical, or of any other nature, are essentially the same (360), it

composition, show some new conditions of that action, evolve new views of the internal arrangements and changes of the substances under decomposition, and perhaps give efficient powers over matter as yet undecomposed

452 For the purpose of rendering the bearings of the different parts of this series of researches more distinct, I shall divide it into several heads

¶ i *New Conditions of Electro-chemical Decomposition*

stances classing with these as conductors, as

[1] Refer to the note after 1047, Series VIII —*Dec.* 1838

fast as it can be produced, and therefore, in relation to quantity, as fast as it could have passed through much shorter portions of the

poles The general form of apparatus used in

and moistened in solution of sulphate of soda, the point of the wire from the machine (representing the positive pole) put upon the litmus paper, and the receiving point from the dis-

volta-electric current

455 The pieces of litmus and turmeric paper were *now* placed each upon a separate plate of

PLATE V

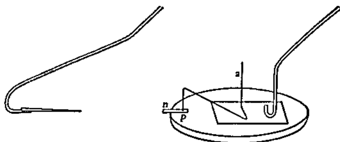


Fig 1

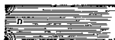


Fig 2

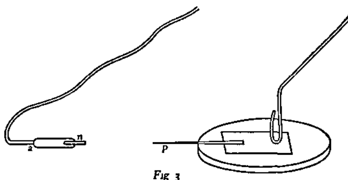


Fig 3

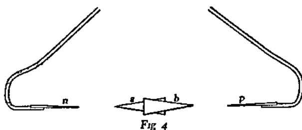


Fig 4

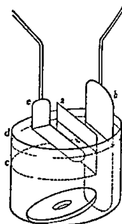


Fig 6

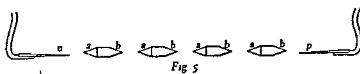


Fig 5

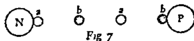


Fig 7

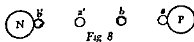


Fig 8

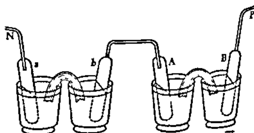


Fig 9

used It was insulated in the air by suspenders of silk, so that the electricity passed through its entire length decomposition took place exactly as in former cases, alkali and acid appearing at the two extremities in their proper places

456 Experiments were then made both with sulphate of soda and iodide of potassium, to as certain if any diminution of decomposing effect was produced by such great extension as those just described of the moist conductor or body under decomposition but whether the contact of the decomposing point connected with the discharging train was made with turmeric paper touching the prime conductor, or with other turmeric paper connected with it through the seventy feet of string, the spot of alkali for an equal number of turns of the machine had equal intensity of colour The same results occurred at the other decomposing wire, whether the salt or the iodide were used and it was fully proved that this great extension of the distance between the poles produced no effect whatever on the amount of decomposition, provided the same *quantity* of electricity were passed in both cases (377)

457 The negative point of the discharging train, the turmeric paper, and the string were then removed, the positive point was left resting upon the litmus paper, and the latter touched by a piece of moistened string held in the hand A few turns of the machine evolved acid at the positive point as freely as before

458 The end of the moistened string, instead of being held in the hand, was suspended by glass in the air On working the machine the electricity proceeded from the conductor through the wire point to the litmus paper, and thence away by the intervention of the string to the air so that there was (as in the last experiment) but one metallic pole still acid was evolved there as freely as in any former case

459 When any of these experiments were repeated with electricity from the negative conductor, corresponding effects were produced whether one or two decomposing wires were used. The results were always constant, considered in relation to the *direction* of the electric current

460 These experiments were varied so as to include the action of only one metallic pole, but that not the pole connected with the machine Turmeric paper was moistened in solution of sulphate of soda, placed upon glass, and connected with the discharging train (292) by a decomposing wire (312), a piece of wet string was hung from it, the lower extremity of which was brought opposite a point connected with the positive prime conductor of the machine The machine was then worked for a few turns, and alkali immediately appeared at the point of the discharging train which rested on the turmeric paper Corresponding effects took place at the negative conductor of a machine

461 These cases are abundantly sufficient to show that electro-chemical decomposition does not depend upon the simultaneous action of two metallic poles, since a single pole might be used, decomposition ensue, and one or other of the elements liberated pass to the pole, according as it was positive or negative In considering the course taken by, and the final arrangement of, the other element, I had little doubt that I should find it had receded towards the other extremity, and that the air itself had acted as a pole, an expectation which was fully confirmed in the following manner

462 A piece of turmeric paper, not more than 0 4 of an inch in length and 0 5 of an inch in width, was moistened with sulphate of soda and placed upon the edge of a glass plate opposite to and about two inches from, a point connected with the discharging train (Pl V, *Fig 1*), a piece of tinfoil, resting upon the same glass plate, was connected with the machine, and also with the turmeric paper, by a decomposing wire *a* (312) The machine was then worked, the positive electricity passing into the turmeric paper at the point *p*, and out at the extremity *n* After forty or fifty turns of the machine, the extremity *n* was examined and the two points or angles found deeply coloured by the presence of free alkali (Pl V, *Fig 2*)

463 A similar piece of litmus paper, dipped in solution of sulphate of soda *n* Pl V, *Fig 3*, was now supported upon the end of the discharging train *a*, and its extremity brought opposite to a point *p*, connected with the conductor of the machine After working the machine for a short time, acid was developed at both the corners towards the point, i e , at both the corners receiving the electricities from the air Every precaution was taken to prevent this acid from being formed by sparks or brushes passing through the air (322) and these, with the accompanying general facts, are sufficient to show that the acid was really the result of electro-chemical decomposition (466)

464 Then a long piece of turmeric paper, large at one end and pointed at the other, was moistened in the saline solution, and immediately connected with the conductor of the machine, so that its pointed extremity was oppo-

site a point upon the discharging train When the machine was worked, alkali was evolved at that point and even when the discharging train was removed, and the electricity left to be diffused and carried off altogether by the air, still alkali was evolved where the electricity left the turmeric paper

465 Arrangements were then made in which no metallic communication with the decomposing matter was allowed, but both poles (if they might now be called by that name) formed of air only A piece of turmeric paper *a*, Pl V, *Fig 4*, and a piece of litmus paper *b*, were dipped in solution of sulphate of soda put *together so as to form one moist pointed conductor, and supported on wax between two needle points, one, p, connected by a wire with the conductor of the machine, and the other, n, with the discharging train The interval in each case between the points was about half an inch* the positive point *p* was opposite the litmus paper the negative point *n* opposite the turmeric The machine was then worked for a time, upon which evidence of decomposition quickly appeared, for the point of the litmus *b* became reddened from acid evolved there, and the point of the turmeric *a* red from a similar and simultaneous evolution of alkali

466 Upon turning the paper conductor round, so that the litmus point should now give off the positive electricity, and the turmeric point receive it, and working the machine for a short time, both the red spots disappeared, and as on continuing the action of the machine no red spot was re-formed at the litmus extremity, it proved *that in the first instance (463) the effect was not due to the action of brushes or mere electric discharges causing the formation of nitric acid from the air* (322)

467 If the combined litmus and turmeric paper in this experiment be considered as constituting a conductor independent of the machine or the discharging train, and the final places of the elements evolved be considered in relation to this conductor, then it will be found that the acid collects at the *negative* or receiving end or pole of the arrangement, and the alkali at the *positive* or delivering extremity

468 Similar litmus and turmeric paper points were now placed upon glass plates, and connected by *a string six feet long, both string and paper being moistened in solution of sulphate of soda; a needle point connected with the machine was brought* opposite the litmus paper point, and another needle point connected with the discharging train brought opposite the turmeric paper On working the machine, acid appeared on the litmus, and alkali on the turmeric paper but the latter was not so abundant as in former cases, for much of the electricity passed off from the string into the air, and diminished the quantity discharged at the turmeric point

469 Finally, a series of four small compound conductors, consisting of litmus and turmeric paper (Pl. V, *Fig 5*) moistened in solution of sulphate of soda, were supported on glass rods, in a line at a little distance from each other between the points *p* and *n* of the machine and discharging train, so that the electricity might pass in succession through them, *entering in at* the litmus points *b*, *b*, and *passing out at the* turmeric points *a*, *a* *On working the machine carefully, so as to avoid sparks and brushes* (322), *I soon obtained evidence of decomposition in each of the moist conductors, for* all the *litmus points exhibited free acid, and the turmeric points equally showed free* alkali

470 On using solutions of iodide of potassium, acetate of lead, &c, similar effects were obtained, but as they were all consistent with the results above described, I refrain from describing the appearances minutely

471 These cases of electro-chemical decomposition are in their nature exactly of the same kind as those affected under ordinary circumstances by the voltaic battery, notwithstanding the great differences as to the presence or absence, or at least as to the nature of the parts usually called poles, and also of the final situation of the elements eliminated *at the electrified boundary surface (467) They indicate at once an internal action of the parts suffering decomposition, and appear to show* that the power which is effectual in separating the elements is exerted there and not at the poles. But I shall defer the consideration of this point for a short time (493, 518), that I may previously consider another supposed condition of electro-chemical decomposition [1]

[1] I find (since making and describing *these results*) *from a note to Sir Humphry Davy's paper* in the *Philosophical Transactions* 1807 p 31 that that philosopher in repeating Wollaston's *experiment of the decomposition of water by common electricity* (327 330) used an arrangement somewhat *like some* of those I have described He *immersed* a guarded platina point connected with the machine in distilled water and dissipated the electricity *from the water into the air by moistened filaments of cotton* In this way he states that he obtained oxygen and hydrogen *separately* from each other This experiment, had I *known of it ought to have been quoted in an earlier* series of these *Researches* (342) but it does not remove any of the *objections I have made* to the use of Wollaston's apparatus as a test of true chemical action (331)

¶ ii *Influence of Water in Electro-chemical Decomposition*

472 It is the opinion of several philosophers, that the presence of water is essential in electro-chemical decomposition, and also for the evolution of electricity in the voltaic battery itself As the decomposing cell is merely one of the cells of the battery, into which particular substances are introduced for the purpose of experiment, it is probable that what is an essential condition in the one case is more or less so in the other The opinion, therefore, that water is necessary to decomposition, may have been founded on the statement made by Sir Humphry Davy that "there are no fluids known, except such as contain water, which are capable of being made the medium of connexion between the metals or metal of the voltaic apparatus" [1] and again, "when any substance rendered fluid by heat, consisting of *water*, oxygen, and inflammable or metallic matter, is exposed to those wires, similar phenomena (of decomposition) occur" [2]

473 This opinion has, I think, been shown by other philosophers not to be accurate, though I do not know where to refer for a contradiction of it. Sir Humphry Davy himself said in 1801,[3] that dry nitre, caustic potash and soda are conductors of galvanism when rendered fluid by a high degree of heat but he must have considered them, or the nitre at least, as not suffering decomposition, for the statements above were made by him eleven years subsequently. In 1826 he also pointed out, that bodies not containing water, as *fused litharge* and *chlorate of potassa*, were sufficient to form, with platina and zinc, powerful electromotive circles;[4] but he is here speaking of the *production* of electricity in the pile, and not of its effects when evolved, nor do his words at all imply that any correction of his former distinct statements relative to *decomposition* was required

474 I may refer to the last series of these *Experimental Researches* (380, 402) as setting the matter at rest, by proving that there are hundreds of bodies equally influential with water in this respect, that amongst binary compounds, oxides, chlorides, iodides, and even sulphurets (402) were effective, and that amongst more complicated compounds, cyanides and salts, of equal efficacy, occurred in great numbers (402)

[1] *Elements of Chemical Philosophy* p 169 &c.
[2] *Ibid* pp 144 145
[3] *Journal of the Royal Institution* 1802 p 53.
[4] *Philosophical Transactions* 1826 p. 406.

475 Water, therefore, is in this respect merely one of a very numerous class of substances, instead of being the *only one* and *essential*, and it is of that class one of the *worst* as to its capability of facilitating conduction and suffering decomposition The reasons why it obtained for a time an exclusive character which it so little deserved are evident, and consist in the general necessity of a fluid condition (394), in its being the *only one* of this class of bodies existing in the fluid state at common temperatures, its abundant supply as the great natural solvent, and its constant use in that character in philosophical investigations, because of its having a smaller interfering, injurious, or complicating action upon the bodies, either dissolved or evolved, than any other substance

476 The analogy of the decomposing or experimental cell to the other cells of the voltaic battery renders it nearly certain that any of those substances which are decomposable when fluid, as described in my last paper (402), would, if they could be introduced between the metallic plates of the pile, be equally effectual with water, if not more so Sir Humphry Davy found that litharge and chlorate of potassa were thus effectual [5] I have constructed various voltaic arrangements, and found the above conclusion to hold good When any of the following substances in a fused state were interposed between copper and platina, voltaic action more or less powerful was produced Nitre, chlorate of potassa carbonate of potassa sulphate of soda, chloride of lead, of sodium, of bismuth, of calcium iodide of lead oxide of bismuth oxide of lead the electric current was in the same direction as if acids had acted upon the metals When any of the same substances, or phosphate of soda, were made to act on platina and iron, still more powerful voltaic combinations of the same kind were produced When either nitrate of silver or chloride of silver was the fluid substance interposed, there was voltaic action, but the electric current was in the *reverse direction*

¶ iii *Theory of Electro-chemical Decomposition*

477 The extreme beauty and value of electro-chemical decompositions have given to that power which the voltaic pile possesses of causing their occurrence an interest surpassing that of any other of its properties for the power is not only intimately connected with the continuance, if not with the production, of the electrical phenomena, but it has furnished us

[5] *Philosophical Transactions* 1826 p. 406.

with the most beautiful demonstrations of the *nature of many compound bodies* has in the hands of Becquerel been employed in compounding substances has given us several new combinations and sustains us with the hope that when thoroughly understood it will produce many more

478 What may be considered as the general *facts of electro-chemical decomposition* are agreed to by nearly all who have written on the subject They consist in the separation of the decomposable substance acted upon into its proximate or sometimes ultimate *principles* whenever both poles of the pile are in contact with that substance in a proper condition in the *evolution of these principles at distant* points i e at the poles of the pile where they are either finally set free or enter into union with the substance of the poles and in the constant determination of the evolved elements or principles to particular poles according to certain well-ascertained laws.

479 *But the views of men of science vary* much as to the nature of the action by which these effects are produced and as it is certain *that we shall be better able to* apply the power when we really understand the manner in which it operates this difference of opinion is a strong inducement to further inquiry I have been led *to hope that the following investigations might* be considered not as an increase of that which is doubtful but a real addition to this branch of knowledge

480 It will be needful that I briefly state the views of electro-chemical decomposition already put forth that their present contradictory and unsatisfactory state may be seen before I give that which seems to me more accurately to agree with facts and I have ventured to discuss them freely trusting that I should give no offence to their high minded authors for I felt convinced that if I were right they would be pleased that their views should serve as stepping-stones for the advance of science and that if I were wrong they would excuse the zeal which misled me since it was exerted for the service of that great cause whose prosperity and progress they have desired

481 Grotthuss in the year 1805 wrote expressly on the decomposition of liquids by voltaic electricity[1] He considers the pile as an electric magnet, i e as an attractive and repulsive agent the poles having *attractive and repelling* powers The pole from whence resinous electricity issues attracts hydrogen and repels oxygen whilst that from which vitreous electricity *proceeds attracts* oxygen and *repels* hydrogen, so that each of the elements of a particle of water, for instance is subject to an attractive and a repulsive force acting in contrary directions, the centres of action of which are reciprocally opposed The action of each force in relation to a molecule of water situated *in the course of the electric current is in the inverse* ratio of the square of the distance at which it is exerted thus giving (it is stated) for such a molecule a *constant force*[2] He explains the appearance of the elements at a distance from each other by referring to a succession of decompositions and recompositions occurring amongst the intervening *particles*[3] and he thinks it probable that those which are about to separate at the poles unite to the two electricities there and in consequence become gases[4]

482 Sir Humphry Davy's celebrated Bakerian Lecture on some chemical agencies of electricity was read *in November 1806*, and is almost entirely occupied in the consideration of *electro-chemical decompositions* The facts are of the utmost value and with the general points established are universally known The *mode of action* by which the effects take place is stated very generally, so generally indeed that probably a *dozen precise* schemes of electro-chemical action might be drawn up differing essentially from each other yet all agreeing with the statement there *given*

483 When Sir Humphry Davy uses more particular expressions he seems to refer the decomposing effects to the *attractions of the* poles This is the case in the general expression of facts given at pp 28 and 29 of the *Philosophical Transactions* for 1807 also at p 30 Again at p 160 of the *Elements of Chemical Philosophy* he speaks of the great attracting powers of the surfaces of the
tions the
positi
fluid
huss[5] ... the attractive and repellent agencies may be communicated from the metallic surfaces throughout the whole of the menstruum,[6] being communicated from one *particle to another particle of the same kind*[7] and diminishing in strength from the place of the poles to the middle point, which is necessarily

[1] *Annales de Chimie* 1806 Vol LVIII, p. 64.

[2] *Ibid* pp 60, 67 also Vol LXIII p 20
[3] *Ibid* Vol LVIII p 68 Vol LXIII p 20
[4] *Ibid* Vol LXIII p 34
[5] *Philosophical Transactions* 1807 pp 29 30.
[6] *Ibid.* p 39
[7] *Ibid.*, p. 29

neutral [1] In reference to this diminution of power at increased distances from the poles he states that in a circuit of ten inches of water solution of sulphate of potassa placed four inches from the positive pole did not decompose whereas when only two inches from that pole it did ren

mented on this subject in 1807 They came to the conclusion that the voltaic current caused decompositions throughout its whole course in the humid conductor not merely as preliminary to the recompositions spoken of by Grotthuss and Davy but producing final separation of the elements in the *course* of the current and elsewhere than at the poles They considered

powerful the nearer they are to their respective poles and state that the positive current is *superior* in power to the negative current [5]

486 M Biot is very cautious in expressing an opinion as to the cause of the separation of the elements of a compound body [6] But as far

positive at the positive pole that state gradually diminishes to the middle distance where the fluid is neutral or not electrical but from

487 M ...

electricity for the time [9] and though it communicates this electricity to the surrounding undecomposed matter with which it is in con

488 This theory implies that decomposition takes place at both poles upon distinct portions of fluid and not at all in the intervening parts The latter serve merely as imperfect conduc-

repulsions [11]

489 M A de la Rive investigated this sub-

ing the metal and leaving the hydrogen or

Ibid p 4?

Ibid 1806 p 383 ... 407 415 ... 83 &c ... edition

Ibid p 636 [10] *Ibid* p 642
Ibid pp 638 642
[9] *Annales de Chimie*, Vol XXVIII p 19..
[11] *Annales de Chimie* Vol XXVIII pp 2..
[12] *Ibid* p 202 [13] *Ibid* p 201
[14] *Ibid* pp 197 198.

others the successive decompositions and recompositions in the whole course of the electricity through the humid conductor,[1] but thinks *the middle parts are in themselves unaltered*, or at least serve only to conduct the two contrary currents of electricity and matter which set off from the opposite poles[2] The decomposition, therefore, of a particle of water, or a particle of salt, may take place at either pole, and when once effected, it is final for the time, *no recombination taking place, except the momentary union of the transferred particle with the electricity be so considered*

491 The latest communication that I am aware of on the subject is by M Hachette its date is October 1832[3] It is incidental to the description of the decomposition of water by the magneto-electric currents (346) One of the results of the experiment is, that "it is not necessary, as has been supposed, that for the chemical decomposition of water, the action of the two *electricities*, positive and negative, *should* be simultaneous"

492 It is more than probable that many other views of electro-chemical decomposition may have been published, and perhaps amongst them some which, differing from those above, might, even in my own opinion, were I *acquainted with them, obviate the necessity for* the publication of my views If such be the case, I have to regret my ignorance of them, and apologize to the authors

493 That electro-chemical decomposition does not depend upon any direct attraction and repulsion of the poles (meaning thereby the metallic terminations either of the voltaic battery, or ordinary electrical machine arrangements (312)), upon the elements in contact *with or near to them, appeared very evident* from the experiments made in air (462, 465, &c.), when the substances evolved did not collect about any poles, but, in obedience to the direction of the current, were evolved, and *I* would say ejected, at the extremities of the decomposing substance But notwithstanding the extreme dissimilarity in the character of air and metals, and the almost total difference existing between them as to their mode of conducting electricity, and becoming charged with *it, it might* perhaps still be contended, although quite hypothetically, that the bounding portions of air were now the surfaces or places of attraction, as the metals had been supposed to be before In illustration of this and other points, I endeavoured to devise an arrangement by which I could decompose a body against a surface of water, as well as against air or metal, and succeeded in doing so unexceptionably in the following manner. As the experiment for very natural reasons requires many precautions, to be successful, and will be referred to hereafter in illustration of the views I shall venture to give, I must describe it minutely

494 *A glass basin (Pl V, Fig 6), four inches* in diameter and four inches deep, had a division of mica *a*, fixed across the upper part so as to descend one inch and a half below the edge, and be perfectly water-tight at the sides a plate of platina *b*, three inches wide, was put into the basin on one side of the division *a*, and retained there by a glass block below, so that any gas produced by it in a future stage of the experiment should not ascend beyond the mica, and cause currents in the liquid on that side A strong solution of sulphate of magnesia was carefully poured without splashing into the basin, until it rose a little above the lower edge of the mica division *a*, great care being taken that the glass or mica on the unoccupied or *c* side of the division in the figure, should not be moistened by agitation of the solution above *the level to which it rose A thin piece* of clear cork, well wetted in distilled water, was then carefully and lightly *placed on* the solution at the *c* side, and distilled water poured gently on to it until a stratum the eighth *of an inch in* thickness appeared over the sulphate of magnesia all was then left for a few minutes, that any solution adhering to the cork might sink away from it, or be removed by the water on which it now floated and then more distilled water was added in a similar manner, until it *reached nearly to the top of* the glass In this way solution of the sulphate occupied the lower part of the glass, and also the upper on the right-hand side of the mica, but on the *left-hand side of the division a stratum of water* from *c* to *d*, one inch and a half in depth, reposed upon it, the two presenting, when looked through horizontally, a comparatively definite plane of contact A second platina pole *e*, was arranged so as to be just under the surface of the water, in a position nearly horizontal, a little inclination being given to it, that gas evolved during decomposition might escape the part immersed was three inches and a half long by one inch wide, and about seven-eighths *of an inch of water intervened* between it and the solution of sulphate of magnesia

[1] *Ibid*, pp 192, 199
[2] *Ibid*, p 200.
[3] *Ibid.*, Vol LI p. 73

495 The latter pole *e* was now connected with the negative end of a voltaic battery of forty pairs of plates four inches square whilst the former pole *b* was connected with the pos tive end There was action and gas evolved at both poles but from the intervention of the pure water the decomposition was very feeble compared to what the battery would have ef fected in a uniform solution After a little while (less than a minute) magnesia also appeared at the negative side *it did not make its appear ance at the negati e metallic pole but in the wa-*

stratum of water upwards in the fluid e and downwards at the side which gradually gave

was altogether an effect of the currents and d d not occur until long after the phenomena looked for were sat sfactor ly ascertained

496 After a little while the voltaic communi cation was broken and the plat na poles re-

traces of alkali nor could anything but pure water be found upon it The pole *b* though drawn through a much greater depth and quan tity of fluid was found so acid as to give abun dant evidence to l tmus paper the tongue and other tests Hence there had been no interfer ence of alkal ne salts in any way undergo ng

ment was repeated again and again and al ways successfully

497 As therefore the substances evolved in cases of electro-chemical decomposition may be made to appear against a r (465 469)— which according to common language is not a conductor nor is decomposed or aga nst wa

sider the phenomena generally as due to the *attraction* or attractive powers of the latter when used in the ord nary way since similar attractions can hardly be imagined in the former instances

498 It may be said that the surfaces of air or of water in these cases become the poles and exert attractive powers but what proof is there of that except the fact that the matters evolved collect there which is the po nt to

poles as centres of attractive and repulsive forces (481) these forces varying inversely as the squares of the distances and says therefore that a part cle placed anywhere between the poles will be acted upon by a constant

by other experiments (505), and in the one quoted by him the effect was doubtless due to some of the many interfering causes of variation which attend such investigations

501 A glass vessel had a platina plate fixed perpendicularly across it, so as to divide it into two cells a head of mica was fixed over it, so as to collect the gas it might evolve during experiments, then each cell, and the space beneath the mica, was filled with dilute sulphuric acid Two poles were provided, consisting each of a platina wire terminated by a plate of the same metal, each was fixed into a tube passing through its upper end by an air-tight joint, that it might be moveable, and yet that the gas evolved at it might be collected The tubes were filled with the acid, and one immersed in each cell Each platina pole was equal in surface to one side of the dividing plate in the middle glass vessel, and the whole might be considered as an arrangement between the poles of the battery of a humid decomposable conductor divided in the middle by the interposed platina diaphragm It was easy, when required, to draw one of the poles further up the tube, and then the platina diaphragm was no longer in the middle of the humid conductor But whether it were thus arranged at the middle, or towards one side, it always evolved a quantity of oxygen and hydrogen equal to that evolved by both the extreme plates [1]

502 If the wires of a galvanometer be terminated by plates, and these be immersed in dilute acid, contained in a regularly formed rectangular glass trough, connected at each end with a voltaic battery by poles equal to the section of the fluid, a part of the electricity will pass through the instrument and cause a certain deflection And if the plates are always retained at the *same distance from each other* and from the sides of the trough, are always parallel to each other, and uniformly placed relative to the fluid, then, whether they are immersed near the middle of the decomposing solution, or at one end, still the instrument will indicate the same deflection, and consequently the same electric influence

503 It is very evident, that when the width of the decomposing conductor varies, as is always the case when mere wires or plates, as poles, are dipped into or are surrounded by solution, no constant expression can be given as to the action upon a single particle placed in the course of the current, nor any conclusion of use, relative to the supposed attractive or repulsive force of the poles, be drawn The force will vary as the distance from the pole varies as the particle is directly between the poles or more or less on one side, and even as it is nearer to or farther from the sides of the containing vessels, or as the shape of the vessel itself varies, and, in fact, by making variations in the form of the arrangement, the force upon any single particle may be made to increase, or diminish or remain constant, whilst the distance between the particle and the pole shall remain the same, or the force may be made to increase or diminish, or remain constant, either as the distance increases or as it diminishes.

504 From numerous experiments, I am led to believe the following general expression to be correct, but I purpose examining it much further, and would therefore wish not to be considered at present as pledged to its accuracy *The sum of chemical decomposition is constant* for any section taken across a decomposing conductor, uniform in its nature, at whatever distance the poles may be from each other or from the section, or however that section may intersect the currents, whether directly across them, or so oblique as to reach almost from pole to pole, or whether it be plane, or curved, or irregular in the utmost degree, provided the current of electricity be retained constant in quantity (377), and that the section passes through every part of the current through the decomposing conductor

505 I have reason to believe that the statement might be made still more general, and expressed thus That *for a constant quantity of electricity, whatever the decomposing conductor may be, whether water, saline solutions, acids fused bodies, &c, the amount of electro-chemical action is also a constant quantity, i e, would always be equivalent to a standard chemical effect founded upon ordinary chemical affinity* I have this investigation in hand, with several others, and shall be prepared to give it in the next series but one of these *Researches*

506 Many other arguments might be adduced against the hypotheses of the attraction of the poles being the cause of electro-chemical decomposition, but I would rather pass on to the view I have thought more consistent with facts, with this single remark, that if decomposition by the voltaic battery depended upon the attraction of the poles, or the parts about them, being stronger than the mutual attrac-

[1] There are certain precautions in this and such experiments, which can only be understood and guarded against by a knowledge of the phenomena to be described in the first part of the Sixth Series of these *Researches*

tion of the particles separated, it would follow that the weakest *electrical* attraction was stronger than, if not the strongest, yet very strong *chemical* attraction, namely, such as exists be-

not impossible, seems in the present state of the subject very unlikely

either the arguments or facts urged against the latter Considering it as stated by the former philosopher, it appears to me to be incompetent to account for the experiments of decomposition against surfaces of air (462, 469) and water (495) which I have described, for if the physical differences between metals and humid conductors, which M de la Rive supposes to account for the transmission of the compound of matter and electricity in the latter, and the transmission of the electricity only with the rejection of the matter in the former, be allowed for a moment, still the analogy of air to metal is, electrically considered so small, that instead of the former replacing the latter (462), an effect the very reverse might have been expected Or if even that were allowed, the experiment with water (495), at once sets the matter at rest, the decomposing pole being now of a substance which is admitted as competent to transmit the assumed compound of electricity and matter

508 With regard to the views of MM Riffault and Chompré (485), the occurrence of decomposition alone in the *course* of the current is so contrary to the well known effects ob-

ories of electro-chemical decomposition, whilst

cases (375) the decomposition is proportionate *to the quantity of electricity passing*, whatever may be its intensity or its source, and that the same is probably true for all cases (377) even when the utmost generality is taken on the one hand and great precision of expression on the other (505)

variety of views taken by philosophers, all agreeing in the effect of the current itself Some philosophers, with Franklin assume but one electric fluid, and such must agree together in the general uniformity and character of the electric current Others assume two electric fluids and here singular differences have arisen

512 MM Riffault and Chompré for instance, consider the positive and negative currents each as causing decomposition, and state that the positive current is *more powerful* than the negative current,[1] the nitrate of soda being, under similar circumstances, decomposed by the former, but not by the latter

513 M Hachette states[2] that ' it is not necessary, as has been believed, that the action of the two electricities, positive and negative, should be simultaneous for the decomposition of water " The passage implying, if I have caught the meaning aright, that one electricity can be obtained, and can be applied in effect-

mentary electric currents, moving in opposite directions, from pole to pole, constitute the ordinary *voltaic current*

515 M Grotthuss is inclined to believe that the elements of water, when about to separate at the poles, combine with the electricities, and

[1] *Annales de Chimie* 1807 Vol LXIII p 84.
[2] *Ibid* 1832 Vol LI p 73
[3] *Ibid* 1825, Vol XXVIII pp. 197, 201.

so become gases M de la Rive's view is the exact reverse of this whilst passing through the fluid, they are, according to him, compounds with the electricities when evolved at the poles, they are de-electrified

516 I have sought amongst the various experiments quoted in support of these views, or connected with electro-chemical decompositions or electric currents, for any which might be considered as sustaining the theory of two electricities rather than that of one, but have not been able to perceive a single fact which could be brought forward for such a purpose or, *admitting the hypothesis of two electricities*, much less have I been able to perceive the slightest grounds for believing that one electricity in a current can be more powerful than the other, or that it can be present without the *other, or that one can be varied or in the slightest* degree affected, without a corresponding variation in the other[1] If, upon the supposition of two electricities, a current of one can be obtained without the other, or the current of one be exalted or diminished more than the other, we might surely expect some variation either of the chemical or magnetical effects, or of both, but no such variations have been observed If a current be so directed that it may act chemically in one part of its course, and magnetically in another, the two actions are always found to take place together A current has not, to *my knowledge, been produced which could act* chemically and not magnetically, nor any which can act on the magnet, and not *at the same time* chemically[2]

517 *Judging from facts only*, there is not as yet the slightest reason for considering the influence which is present in what we call the electric current,—whether in metals or fused bodies *or humid conductors, or even in air*, flame, and rarefied elastic media,—as a compound or complicated influence It has never been resolved into simpler or elementary influences, and may perhaps best be conceived *of as an axis of power having contrary forces, exactly equal in amount, in contrary directions*

518. Passing to the consideration of electro-chemical decomposition, it appears to me that the effect is produced by an *internal corpuscular action*, exerted according to the direction of the electric current, and that it is due to a force either *super added to, or giving direction to the ordinary chemical affinity* of the bodies present The body under decomposition may be considered as a mass of acting particles, all those which are included in the course of the electric current contributing to the final effect and it is because the ordinary chemical affinity is relieved weakened, or partly neutralized by the influence of the electric current in one direction parallel to the course of the latter, and strengthened or added to in the opposite direction, that the combining particles have a tendency to pass in opposite courses

519 *In this view the effect is considered as essentially dependent* upon the *mutual chemical affinity* of the particles of opposite kinds Particles *a a* Pl V, *Fig 7*, could not be transferred or travel from one pole N towards the other P, *unless they found particles of the opposite kind* *b b* ready to pass in the contrary direction for it is by virtue of their increased affinity for those particles, combined with their diminished affinity for such as are behind them in their course, that they are urged forward and when any one particle *a*, Pl V, *Fig 8*, arrives at the pole, it is excluded or set free, because the *particle b of the opposite kind, with which it was* the moment before in combination, has, under the superinducing influence of the current a greater attraction for the particle *a′*, which is before it in its course, than for the particle *a* *towards which its affinity has been weakened*

520 As far as regards any single compound particle, the case may be considered as analogous to one of ordinary decomposition, *for, in Fig 8, a* may be conceived to be expelled from the compound *a b* by the superior attraction of *a′* for *b* that superior attraction belonging to it in consequence of the relative position of *a b* *and a to the direction of the axis* of electric power (517) superinduced by the current But as all the compound particles in the course of the current, except those actually in contact with the poles, act conjointly, and consist of elementary particles, which, whilst they are in one direction expelling, are in the other being expelled the case becomes more complicated, *but not more difficult of comprehension*

521 It is not here assumed that the acting particles must be in a right line between the poles The lines of action which may *be supposed* to represent the electric currents passing through a decomposing liquid, have in many experiments very irregular forms, and even in the simplest case of two wires or points im-

[1] See now in relation to this subject, 1627–1645 —*Dec* 1838

[2] Thermo-electric currents are of course no exception because when they fail to act chemically they also fail to be currents

mersed as poles in a drop or larger single portion of fluid, *these lines must diverge* rapidly from the poles, and the direction in which the chemical affinity between particles is most powerfully modified (519, 520) will vary with the *direction of* these lines, according *constantly* with them But even in reference to these lines or currents, it is not supposed that the particles which mutually affect each other must of necessity be *parallel to them*, but *only* that they shall accord generally with their direction Two particles, placed in a line perpendicular to the electric current passing in any particular *place*, are not supposed *to have their* ordinary chemical relations towards each other affected but as the line joining them is inclined one way to the current their mutual affinity is increased, *as it is inclined in the* other direction it is diminished, and the effect is a maximum, when that line is parallel to the current [1]

522 That the actions, of whatever kind they may be, take place *frequently in oblique directions* is evident from the circumstance of those particles being included which in numerous *cases* are not in a line between the poles Thus, when *wires are used as poles* in a glass of solution, the decompositions and recompositions occur to the right or left of the direct line between the poles, and indeed in every part to which the currents extend, as is proved by many experiments, and must therefore often occur between particles obliquely placed as respects the current itself, and when a *metallic* vessel containing the solution is made one pole, whilst a mere point or wire is used for the other, the decompositions and recompositions must *frequently be still more* oblique to the course of the currents.

523 The theory which I have ventured to put forth (almost) requires an admission, that in a compound body capable of electro-chemical decomposition the elementary particles have a mutual relation to and influence upon each other, extending beyond *those with* which they are immediately combined Thus in water, a particle of hydrogen in combination with oxygen is considered as not altogether *indifferent* to other particles of oxygen, although they are combined with other particles of hydrogen, but to have an affinity or attraction *towards* them, which, though it does *not* at all approach in force, under ordinary circumstances, to that by which it is combined with its own particle, can, under the electric influence, exerted in a definite direction, be made even to surpass it This general relation of particles already in combination to other particles with which they are not combined, is sufficiently *distinct in* numerous results *of a purely chemical* character, especially in those where partial decompositions only take place, and in Berthollet s experiments on the effects of quantity upon *affinity* and *it probably* has a direct relation to, and connexion with, attraction of aggregation, both in solids and fluids It is a remarkable circumstance, that in gases and *vapours*, where *the attraction of aggregation* ceases, there likewise the decomposing powers of electricity apparently cease, and there also the chemical action of quantity is no longer *evident It seems* not *unlikely that the inability* to suffer decomposition in these cases may be dependent upon the absence of that mutual attractive relation of the particles which is the *cause of aggregation*

524 I hope I have now distinctly stated, although in general terms, the view I entertain of the cause of electro-chemical *decomposition, as far as that cause can at present be traced and understood* I conceive the effects to arise from forces which are *internal*, relative to the matter under *decomposition*—and not *external, as* they might be considered, if directly dependent upon the poles I suppose that the effects are due to a modification, by the electric current, of *the chemical affinity* of the particles through or by which that current is passing, giving them the power of acting more forcibly in one direction than in another, and *consequently* making them *travel by a series* of successive decompositions and recompositions in opposite directions, and finally causing their expulsion or exclusion at *the boundaries of the* body under decomposition, in the direction of the current, *and that* in *larger or* smaller quantities, according as the current is more or *less powerful* (377) I think therefore, it would be more philosophical, and more directly expressive of the facts, to speak of such a body in relation to *the current passing* through it rather than to the *poles*, as they are usually called in contact with it and say that whilst under decomposition, oxygen, chlorine, iodine, acids, &c, are rendered at its negative extremity, and combustibles, metals, alkalies, bases, &c, at its positive extremity (467) *I do not believe that a substance can be transferred in the electric* current beyond the point where it to find particles with which it can

[1] In reference to this subject see now electrolytic induction and discharge, Series XII ¶ viii. 1343–1351, &c —*Dec* 1838

and I may refer to the experiments made in air (465) and in water (495), already quoted, for facts illustrating these views in the first instance to which I will now add others

525 In order to show the dependence of the decomposition and transfer of elements upon the chemical affinity of the substances present, experiments were made upon sulphuric acid in the following manner Dilute sulphuric acid was prepared its specific gravity was 1021 2 A solution of sulphate of soda was also prepared, of such strength that a measure of it contained exactly as much sulphuric acid as an equal measure of the diluted acid just referred to A solution of pure soda and another of pure ammonia, were likewise prepared of such strengths that a measure of either should be exactly neutralized by a measure of the prepared sulphuric acid

526 Four glass cups were then arranged, as in Pl V, *Fig 9*, seventeen measures of the free sulphuric acid (525) were put into each of the vessels *a* and *b*, and seventeen measures of the solution of sulphate of soda into each of the vessels A and B Asbestos which had been well-washed in acid, acted upon by the voltaic pile, well washed in water, and dried by pressure, was used to connect *a* with *b* and A with B, the portions being as equal as they could be made in quantity, and cut as short as was consistent with their performing the part of effectual communications *b* and A were connected by two platina plates or poles soldered to the extremities of one wire, and the cups *a* and B were by similar platina plates connected with a voltaic battery of forty pairs of plates four inches square, that in *a* being connected with the negative, and that in B with the positive pole The battery, which was not powerfully charged, was retained in communication above half an hour In this manner it was certain that the same electric current had passed through *a b* and A B, and that in each instance the same quantity and strength of acid had been submitted to its action, but in one case merely dissolved in water, and in the other dissolved and also combined with an alkali

527 On breaking the connexion with the battery, the portions of asbestos were lifted out, and the drops hanging at the ends allowed to fall each into its respective vessel The acids in *a* and *b* were then first compared, for which purpose two evaporating dishes were balanced, and the acid from *a* put into one, and that from *b* into the other, but as one was a little heavier than the other, a small drop was transferred from the heavier to the lighter, and the two rendered equal in weight Being neutralized by the addition of the soda solution (525), that from *a*, or the negative vessel, required 15 parts of the soda solution, and that from *b*, or the positive vessel, required 16 3 parts That the sum of these is not 34 parts is principally due to the acid removed with the asbestos, but taking the mean of 15 65 parts, it would appear that a twenty-fourth part of the acid originally in the vessel *a* had passed, through the influence of the electric current, from *a* into *b*

528 In comparing the difference of acid in A and B, the necessary equality of weight was considered as of no consequence, because the solution was at first neutral, and would not, therefore, affect the test liquids, and all the evolved acid would be in B, and the free alkali in A The solution in A required 3 2 measures of the prepared acid (525) to neutralize it and the solution in B required also 3 2 measures of the soda solution (525) to neutralize it As the asbestos must have removed a little acid and alkali from the glasses, these quantities are by so much too small, and therefore it would appear that about a tenth of the acid originally in the vessel A had been transferred into B during the continuance of the electric action

529 In another similar experiment, whilst a thirty-fifth part of the acid passed from *a* to *b* in the free acid vessels, between a tenth and an eleventh passed from A to B in the combined acid vessels Other experiments of the same kind gave similar results

530. The variation of electro-chemical decomposition, the transfer of elements and their accumulation at the poles, according as the substance submitted to action consists of particles opposed more or less in their chemical affinity, together with the consequent influence of the latter circumstances, are sufficiently obvious in these cases, where *sulphuric acid* is acted upon in the *same quantity* by the *same* electric current, but in one case opposed to the comparatively weak affinity of water for it, and in the other to the stronger one of soda In the latter case the quantity transferred is from two and a half to three times what it is in the former, and it appears therefore very evident that the transfer is greatly dependent upon the mutual action of the particles of the decomposing bodies[1]

531 In some of the experiments the acid from the vessels *a* and *b* was neutralized by ammonia, then evaporated to dryness, heated to redness, and the residue examined for sulphates.

[1] See the note to 675.—*Dec* 1838.

In these cases more sulphate was always obtained from *a* than from *b* showing that it had been impossible to exclude saline bases (derived

ly transferred by relation to the water present

532 I endeavoured to arrange certain experiments by which saline solutions should be decomposed against surfaces of water and at first worked with the electric machine upon a piece of bibulous paper, or asbestos moistened in the solution, and in contact at its two extremities with pointed pieces of paper moistened in pure water which served to carry the electric current to and from the solution in the middle piece. But I found numerous interfering difficulties Thus the water and solutions in the pieces of paper could not be prevented from mingling at the point where they touched Again, sufficient acid could be derived from the paper connected with the discharging train or it may be even from the air itself, under the influence of electric action to neutralize the alkali developed at the positive extremity of the decomposing solution, and so not merely prevent its appearance, but actually transfer it on to the metal termination and in fact when the paper points were not allowed to touch there and the machine was worked until alkali was evolved at the delivering or positive end of the turmeric paper, containing the sulphate of soda solution, it was merely necessary to place the opposite receiving point of the paper connected with the discharging train which had been moistened by distilled water, upon the brown turmeric point and press them together when the alkaline effect immediately disappeared

533 The experiment with sulphate of magnesia already described (495) is a case in point, however, and shows most clearly that the sul

continue its progress towards the negative pole

534. The theory I have ventured to put forth appears to me to explain all the prominent features of electro-chemical decomposition in a satisfactory manner

except at them, every particle finds other particles having a contrary tendency with which it can combine

536 Then it explains why in numerous cases, the elements or evolved substances are not *retained* by the poles and this is no small difficulty in those theories which refer the decomposing effect directly to the attractive power of the poles If, in accordance with the usual theory, a piece of platina be supposed to have sufficient power to attract a particle of hydrogen from the particle of oxygen with which it was the instant before combined, there seems

does not do so but allows it to escape freely

show no particular tendency to combine with

the effect appears to be a natural consequence

538 The theory accounts for the *transfer of*

rendered fluid by heat (380, 402),

conjunction with the experiments in air, led to its construction. Such cases as the former where *binary compounds of easy decomposability* are acted upon, are perhaps the best to illustrate *the theory.*

539. Chloride of lead, for instance, fused in a bent tube (400), and decomposed by platina wires, evolves lead, passing to what is usually called the negative pole, and chlorine, which being evolved at the positive pole, is in part set free, and in part combines with the platina. The chloride of platina formed, being soluble in the chloride of lead, is subject to decomposition, and the platina itself is gradually transferred across the decomposing matter, and found with the lead at the negative pole.

540. Iodide of lead evolves abundance of lead at the negative pole, and abundance of iodine at the positive pole.

541. Chloride of silver furnishes a beautiful instance, especially when decomposed by silver wire poles. Upon fusing a portion of it on a piece of glass, and bringing the poles into contact with it, there is abundance of silver evolved at the negative pole, and an equal abundance absorbed at the positive pole, *for no chlorine is* set free: and by careful management, the negative wire may be withdrawn from the fused globule as the silver is reduced there, the latter serving as the continuation of the pole, until a wire or thread of revived silver, five or six inches in length, is produced; at the same time the silver at the positive pole is as rapidly dissolved by the chlorine, which seizes upon it, so that the wire has to be continually advanced as it is melted away. The whole experiment includes the action of only two elements, silver and chlorine, and illustrates in a beautiful manner their progress in opposite directions, parallel to the electric current, which is for the time giving a uniform general direction to their mutual affinities (524).

542. *According to my theory, an element or* a substance not decomposable under the circumstances of the experiment, (as for instance, a dilute acid or alkali), should not be transferred, or pass from pole to pole, unless it be in chemical relation to some other element or substance tending to pass in the opposite direction, for the effect is considered as essentially due to the mutual relation of such particles. But the theories attributing the determination of the elements to the attractions and repulsions of the poles require no such condition, i.e., there is no reason apparent why the attraction of the positive pole, and the repulsion of the negative pole, upon a particle of free acid, placed in water between them, should not (*with equal currents of electricity*) be as strong as if that particle were previously combined with alkali; *but, on the contrary, as they have* not a powerful chemical affinity to overcome, *there is every reason to suppose they would be* stronger, and would sooner bring the acid to rest at the positive pole.[1] Yet such is not the case, as has been shown by the experiments on free and combined acid (526, 528).

543. Neither does M. de la Rive's theory, as I understand it, *require* that the particles should be in combination: it does not even admit where there are two sets of particles capable of combining with and passing by each other, that they do combine, but supposes that they travel as separate compounds of matter and electricity. Yet in fact the free substance *can not* travel, the combined one *can*.

544. It is very difficult to find cases amongst solutions or fluids which shall illustrate this point, because of the difficulty of finding two fluids which shall conduct, shall not mingle, and in which an element evolved from one shall not find a combinable element in the other. *Solutions* of acids or alkalies will not answer, because they exist by virtue of an attraction; and increasing the solubility of a body in one direction, and diminishing it in the opposite, is just as good a reason for transfer as modifying the affinity between the acids and alkalies themselves.[2] Nevertheless the case of sulphate of magnesia is in point (494, 495), and shows that *one element or principle only* has no power of transference or of passing towards either pole.

545. Many of the metals, however, in their solid state, offer very fair instances of the kind required. Thus, if a plate of platina be used as the positive pole in a solution of sulphuric acid, oxygen will pass towards it, and so will acid; but these are not substances having such chemical relation to the platina as, even under the favourable condition superinduced by the current (518, 524), to combine with it; the platina therefore remains where it was first placed, and has no tendency to pass towards the negative pole. But if a plate of iron, zinc or copper be substituted for the platina, then the oxygen and acid can combine with these, and the metal immediately begins to travel (as an oxide) to the opposite pole, and is finally deposited there.

[1] Even Sir Humphry Davy considered the attraction of the pole as being communicated from one particle to another of the *same* kind (483).

[2] See the note to 675.—*Dec.* 1838.

Or if, retaining the platina pole, a fused chloride, as of lead, zinc, silver, &c , be substituted for the sulphuric acid, then, as the platina finds an element it can combine with, it enters into union, acts as other elements do in cases of voltaic decomposition, is rapidly transferred across the melted matter, and expelled at the negative pole

546 I can see but little reason in the theories referring the electro chemical decomposition to the attractions and repulsions of the poles, and I can perceive none in M de la Rive s theory, why the metal of the positive pole should not be transferred across the intervening conductor, and deposited at the negative pole, even when it cannot act chemically upon the element of the fluid surrounding it It cannot be referred to the attraction of cohesion preventing such an effect for if the pole be made of the lightest spongy platina, the effect is the same Or if gold precipitated by sulphate of iron be diffused through the solution, still accumulation of it at the negative pole will not take place, and yet in it the attraction of cohesion is almost perfectly overcome, the particles are so small as to remain for hours in suspension, and are perfectly free to move by the slightest impulse towards either pole, and *if in relation* by chemical affinity to any substance present, are powerfully determined to the negative pole[1]

547 In support of these arguments it may be observed, that as yet no determination of a substance to a pole, or tendency to obey the electric current, has been observed (that I am

taic battery, terminated by platina poles, but not the slightest tendency of the charcoal to

the negative pole could be observed Sublimed sulphur was diffused through similar acid and submitted to the same action, a silver plate being used as the negative pole, but the sulphur had no tendency to pass to that pole, the silver was not tarnished, nor did any sulphuretted hydrogen appear The case of magnesia and water (495, 533), with those of comminuted metals in certain solutions (546), are also of this kind, and, in fact substances which have the instant before been powerfully determined towards the pole, as magnesia from sulphate of magnesia, become entirely *indifferent to it* the moment they assume their independent state, and pass away, diffusing themselves through the surrounding fluid

548 There are, it is true, many instances of insoluble bodies being acted upon, as glass sulphate of baryta, marble, slate basalt, &c , but they form no exception, for the substances they give up are in direct and strong relation as to chemical affinity with those which they find in the surrounding solution, so that these decompositions enter into the class of ordinary effects

549 It may be expressed as a general consequence, that the more directly bodies are opposed to each other in chemical affinity, the

our chemical elements

550 Some of the most beautiful and surpris-

earths through acids[1] and the way in which substances having the most powerful attractions for each other were thus prevented from combining, or, as it is said, had their natural affinity destroyed or suspended throughout the whole of the circuit, excited the utmost astonishment But if I be right in the view I have taken of the effects, it will appear, that that which made the *wonder*, is in fact the *essential condition* of transfer and decomposition, and that the more alkali there is in the course of an acid, the more will the transfer of that acid be *facilitated from pole to pole, and perhaps* a better illustration of the difference between the theory I have ventured, and those previously existing, cannot be offered than the views they respectively give of such facts as these

551 The instances in which sulphuric acid could not be passed through baryta, or baryta through sulphuric acid,[2] because of the precipitation of sulphate of baryta enter within the pale of the law already described (380, 412), by which liquidity is so generally required for conduction and decomposition In assuming the solid state of sulphate of baryta, these bodies became virtually non conductors to electricity of so low a tension as that of the voltaic battery, and the power of the latter over them was *almost infinitely diminished*

552 The theory I have advanced accords in a most satisfactory manner with the fact of an element or substance finding its place of rest, or rather of evolution sometimes at one pole and sometimes at the other Sulphur illustrates this effect very well[3] When sulphuric acid is decomposed by the pile, sulphur is evolved at the negative pole, but when sulphuret of silver is decomposed in a similar way (436), then the sulphur appears at the positive pole and if a hot platina pole be used so as to vaporize the sulphur evolved in the latter case, then the relation of that pole to the sulphur is exactly the same as the relation of the same pole to oxygen upon its immersion in water In both cases the *element evolved is* liberated at the pole, but not retained by it, but by virtue of its elastic, uncombinable, and immiscible condition passes away into the surrounding medium The sulphur is evidently determined in these opposite directions by its opposite chemical relations to oxygen and silver, and it is to such relations generally that I have referred all electro-chemical phenomena Where they do not exist no electro-chemical action can take place Where they are strongest, it is most powerful where they are reversed, the direction of transfer of the substance is reversed with them

553 *Water* may be considered as one of those substances which can be made to pass to *either* pole When the poles are immersed in dilute sulphuric acid (527), acid passes towards the positive pole, and water towards the negative pole, but when they are immersed in dilute al*kali, the alkali passes towards the negative* pole, and water towards the positive pole

554 Nitrogen is another substance which is considered as determinable to either pole but in consequence of the numerous compounds which it forms, some of which pass to one pole, and some to the other, I have not always found it easy to determine the true circumstances of its appearance A pure strong solution of ammonia is so bad a conductor of electricity that it is scarcely more decomposable than pure water but if sulphate of ammonia be dissolved in it then decomposition takes place very well, nitrogen almost pure, and in some cases quite is evolved at the positive pole, and hydrogen at the negative pole

555 *On the other hand, if a strong solution* of nitrate of ammonia be decomposed, oxygen appears at the positive pole, and hydrogen with sometimes nitrogen, at the negative pole If fused nitrate of ammonia be employed, hydrogen appears at the negative pole, mingled with a little nitrogen Strong nitric acid yields plenty of oxygen at the positive pole, but no gas (only nitrous acid) at the negative pole Weak nitric acid yields the oxygen and hydrogen of the water present, the acid apparently remaining unchanged Strong nitric acid with nitrate of ammonia dissolved in it, yields a gas at the negative pole, of which the greater part is hydrogen, but apparently a little nitrogen is present I believe, that in some of these cases a little nitrogen appeared at the negative pole I suspect however, that in all these, and in all former cases, the appearance of the nitrogen at the positive or negative pole is entirely a secondary effect, and not an immediate consequence of the decomposing power of the electric current[4]

556 A few observations on what are called the *poles* of the voltaic battery now seem necessary. The poles are merely the surfaces or

[1] *Ibid* p 24 &c [2] *Ibid* p 25 &c
[3] At 681 and 757 of Series V it will be found corrections of the statement here made respecting sulphur and sulphuric acid At present there is no well-ascertained fact which proves that the same body can go directly to *either* of the two poles at pleasure —*Dec 1838*

[4] Refer for proof of the truth of this supposition to 748, 752 &c.—*Dec* 1838

doors by which the electricity enters into or passes out of the substance suffering decomposition They limit the extent of that substance in the *course of the electric current, being its terminations* in that direction hence the elements evolved pass so far and no farther

557 Metals make admirable poles, in consequence of their high conducting power, their *immiscibility with the substances generally acted upon*, their solid form, and the opportunity afforded of selecting such as are not chemically acted upon by ordinary substances

558 Water makes a pole of difficult application except in a few cases (494), because of its small conducting power, its miscibility with most of the substances acted upon, and its general relation to them in respect to chemical affinity It consists of elements, which in their electrical and chemical relations are directly and powerfully opposed, yet combining to produce a body more neutral in its character than any other. So that there are but few substances which do not come into relation, by chemical affinity, with water or one of its elements and therefore either the water or its elements are transferred and assist in transferring the infinite variety of bodies which, in association with it, can be placed in the course of the electric current Hence the reason why it so rarely happens that the evolved substances rest at the first surface of the water, and why it therefore does not exhibit the ordinary action of a pole

559 Air, however, and some gases are free from the latter objection, and may be used as poles in many cases (461, &c), but, in consequence of the extremely low degree of conducting power belonging to them, they cannot be employed with the voltaic apparatus This limits their use, for the voltaic apparatus is the only one as yet discovered which supplies sufficient quantity of electricity (371, 376) to effect electro-chemical decomposition with facility

560 When the poles are liable to the chemical action of the substances evolved, either simply in consequence of their natural relation to them, or of that relation aided by the influence of the current (518), then they suffer corrosion, and the parts dissolved are subject to transference, *in the same manner as the particles* of the body originally under decomposition An immense series of phenomena of this kind might be quoted in support of the view I have taken of the cause of electro-chemical decomposition, and *the transfer and evolution* of the elements Thus platina being made the positive and negative poles in a solution of sulphate of soda, has no affinity or attraction for the oxygen, hydrogen acid, or alkali evolved, and refuses to combine with or retain them *Zinc can combine with the* oxygen and acid, at the positive pole it does combine, and immediately begins to travel as oxide towards the negative pole Charcoal, which cannot combine with the metals if made the negative pole *in a metallic solution* refuses to unite to the bodies which are ejected from the solution upon its surface but if made the positive pole in a dilute solution of sulphuric acid, it is capable of combining with the oxygen evolved there, and consequently unites with it producing both carbonic acid and carbonic oxide in abundance

561 A great advantage is frequently supplied by the opportunity afforded amongst the metals of selecting a substance for the pole, which shall or shall not be acted upon by the elements to be evolved The consequent use of platina is notorious In the decomposition of sulphuret of silver and other sulphurets, a positive silver pole is superior to a platina one, because in the *former case the sulphur evolved* there combines with the silver, and the decomposition of the original sulphuret is rendered evident whereas in the latter case it is dissipated, and the assurance of its separation at the pole not easily obtained

562 The effects which take place when a succession of conducting decomposable and undecomposable substances are placed in the electric circuit, as, for instance, of wires and *solutions or of air and solutions* (465, 469), are explained in the simplest possible manner by the theoretical view I have given In consequence of the reaction of the constituents of each portion of decomposable matter, affected as they are by *the supervention of the electric current* (524), portions of the proximate or ultimate elements proceed in the direction of the current as far as they find matter of a contrary kind capable of effecting their transfer, and *being equally affected by them* and where they cease to find such matter, they are evolved in their free state, i e , upon the surfaces of metal or air bounding the extent of decomposable matter in the direction of the current

563 Having thus given my theory of the mode in which electro-chemical decomposition is effected, I will refrain for the present from entering upon the numerous general considerations which it suggests wishing first to submit it to the test of publication and discussion.

Royal Institution, June 1833

PLATE VI

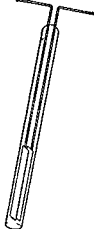

Fig 1


Fig 2

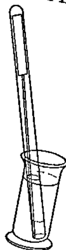
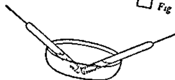

Fig 3


Fig 4


Fig


Fig 7

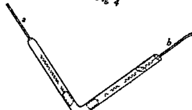


Fig 8

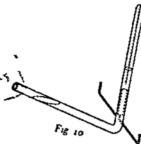

Fig 10


Fig 13



Fig. 16

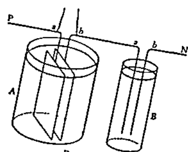
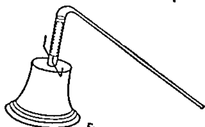


Fig 12


Fig 11

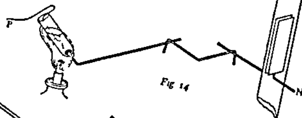


Fig 14


Fig 15

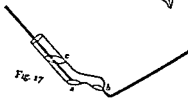


Fig 17

SIXTH SERIES

§ 12 *On the Power of Metals and Other Solids to Induce the Combination of Gaseous Bodies*

RECEIVED NOVEMBER 30 1833 READ JANUARY 11 1834

564 THE conclusion at which I have arrived in the present communication may seem to render the whole of it unfit to form part of a series of researches in electricity since remarkable as the phenomena are the power which produces them is not to be considered as of an electric origin otherwise than as all attraction of particles may have this subtile agent for their common cause But as the effects investigated arose out of electrical researches as they are directly connected with other effects which are of an electric nature and must of necessity be understood and guarded against in a very [illegible]

565 Believing that I had proved (by experiments hereafter to be described [705]) the constant and definite chemical action of a certain quantity of electricity whatever its intensity might be or however the circumstances of its transmission through either the body under decomposition or the more perfect conductors [illegible]

[illegible]

appearance were these A glass tube about twelve inches in length and ¾ths of an inch in diameter had two platina poles fixed into its upper hermetically sealed extremity the poles where they passed through the glass were of wire but terminated below in plates which were soldered to the wires with gold (Pl VI *Fig 1*) The tube was filled with dilute sulphuric acid and inverted in a cup of the same fluid a voltaic battery was connected with the

[illegible]

mediately began to diminish and in about five hours only 13½ parts remained and these ultimately disappeared

567 It was found by various experiments that this effect was not due to the escape or solution of the gas nor to recombination of the oxygen or hydrogen in consequence of any peculiar condition *they* might be supposed to possess under the circumstances but to be occas [illegible]

[illegible] ducing them into separate tubes containing

[illegible] ble kind took place between the positive pole with oxygen or hydrogen alone

568 These experiments reduced the phenomena to the consequence of a power possessed by the platina after it had been the positive pole of a voltaic pile of causing the combination of [illegible]

[illegible] evolved in the cases of electro-chemical decomposition required in the fourteenth section of these Researches

569 Several platina plates were prepared (Pl VI *Fig 2*) They were nearly half an inch wide and two inches and a half long some [illegible]

[illegible] pure gold Then a number of glass tubes were

[1] Or Voltameter —*Dec* 1838

prepared they were about nine or ten inches in length, ⅝ths of an inch in internal diameter, were sealed hermetically at one extremity, and were graduated Into these tubes was put a mixture of two volumes of hydrogen and one of oxygen at the water pneumatic trough and when one of the plates described had been connected with the positive or negative pole of the voltaic battery for a given time, or had been otherwise prepared, it was introduced through the water into the gas within the tube, the whole set aside in a test glass (Pl VI, *Fig 3*), and left for a longer or shorter period, that the action might be observed

570 The following result may be given as an *illustration of the phenomenon to be investigated* Diluted sulphuric acid, of the specific gravity 1 336, was put into a glass jar in which was placed also a large platina plate, connected with the negative end of a voltaic battery of forty pairs of four-inch plates, with double coppers, and moderately charged One of the plates above described (569) was then connected with the positive extremity, and immersed in the same jar of acid for five minutes after which it was separated from the battery, washed in distilled water, and introduced through the water of the pneumatic trough into a tube containing the mixture of oxygen and hydrogen (569) The volume of gases immediately began to lessen, the diminution proceeding more and more rapidly until about ¾ths of the mixture had disappeared The upper end of the tube became quite warm, the plate itself so hot that the water boiled as it rose over it and in less than a minute a cubical inch and a half of the gases were gone, having been combined by the power of the platina, and converted into water

571 This extraordinary influence acquired by the platina at the positive pole of the pile, is exerted far more readily and effectively on oxygen and hydrogen than on any other mixture of gases that I have tried One volume of nitrous gas was mixed with a volume of hydrogen, and introduced into a tube with a plate which had been made positive in the dilute sulphuric acid for four minutes (570) There was no sensible action in an hour being left for thirty-six hours, there was a diminution of about one-eighth of the whole volume Action had taken place, but it had been very feeble

572 A mixture of two volumes of nitrous oxide with one volume of hydrogen was put with a plate similarly prepared into a tube (569, 570) *This also showed no action immediately*, but in thirty-six hours nearly a fourth of the whole had disappeared, i e, about half of a cubical inch By comparison with another tube *containing the same mixture without a plate*, it appeared that a part of the diminution was due to solution, and the other part to the power of the platina, but the action had been very slow and feeble

573 A mixture of one volume olefiant gas[1] and three volumes oxygen was not affected by such a platina plate even though left together for several days (640, 641)

574 A mixture of two volumes carbonic oxide and one volume oxygen was also unaffected by the prepared platina plate in several days (645, &c)

575 A mixture of equal volumes of chlorine and hydrogen was used in several experiments, with plates prepared in a similar manner (570) Diminution of bulk soon took place but when *after thirty six hours the experiments* were examined, it was found that nearly all the chlorine had disappeared, having been absorbed principally by the water, and that the original volume of hydrogen remained unchanged No combination of the gases, therefore, had here taken place

576 Reverting to the action of the prepared plates on mixtures of oxygen and hydrogen (570), I found that the power, though gradually *diminishing in all cases, could still be retained* for a period, varying in its length with circumstances When tubes containing plates (569) were supplied with fresh portions of mixed *oxygen and hydrogen* as the previous portions were condensed, the action was found to continue for above thirty hours, and in some cases slow combination could be observed even after eighty hours but the continuance of the action greatly depended upon the purity *of the* gases used (638)

577 Some plates (569) were made positive for four minutes in dilute sulphuric acid *of specific gravity 1.336 they were rinsed in distilled* water after which two were put into a small bottle and closed up, whilst others were left exposed to the air The plates preserved in the limited portion of air were found to retain their power after eight days, but those exposed *to* the atmosphere had lost their force almost entirely in twelve hours, and in some situations, where currents existed, in a much shorter time

578 Plates were made positive *for five minutes* in sulphuric acid, specific gravity 1.336. One of these was retained in similar acid for eight minutes after separation from the battery it then acted on mixed oxygen and hydro-

[1] *Olefiant gas* now known as *ethylene*.—ED

gen with apparently undiminished vigour Others were left in similar acid for forty hours and [illegible]

579 The effect of a solution of caustic potas- [illegible]

plate became much heated, and I expected the temperature would have risen to ignition

580 When similarly prepared plates (569) had been put into distilled water for forty hours, and then introduced into mixed oxygen and hydrogen they were found to act but very slowly and feebly as compared with those which had been preserved in acid or alkali When, however, the quantity of water was but small, the power was very little impaired after three or four days As the water had been retained in a wooden vessel portions of it were redistilled in glass and this was found to preserve prepared plates for a great length of time Prepared plates were put into tubes with this water and closed up some of them, taken out at the end of twenty four days were found very active on mixed oxygen and hydrogen others, which were left in the water for fifty three days, were still found to cause the combination of the [illegible]

always occurred It must not, however, be unnoticed that the purer the gases subjected to the action of the plate the longer was its combining power retained With the mixture evolved at the poles of the voltaic pile, in pure dilute sulphuric acid it continued longest, and [illegible]

positive pole of the pile affected its power very curiously A plate which had been a positive pole [illegible]

ing in the course of a minute or two, ignited, and would generally explode the gases Occasionally the time occupied in bringing on the action extended to eight or nine minutes and sometimes even to forty minutes and yet ignition and explosion would result This effect is due to the removal of a portion of acid which otherwise adheres firmly to the plate [1]

583 Occasionally the platina plates (569), [illegible] pole of the bat- [illegible]

tubes containing the gas were opened in the air for an instant and the plates put in dry but no sensible difference in action was perceived, except that it commenced sooner

584 The power of heat in altering the action of the prepared platina plates was also tried (595) Plates which had been rendered positive [illegible]

taining a little acid, or having a [illegible]

[1] In proof that this is the case refer to 1038 *Dec* 1838

salt, or other extraneous matter, had been placed, then the power of the plate was quickly and greatly diminished (634, 636)

585 This remarkable property was conferred upon platina when it was made the positive pole in sulphuric acid of specific gravity 1.336, or when it was considerably weaker, or when stronger, even up to the strength of oil of vitriol Strong and dilute nitric acid, dilute acetic acid solutions of tartaric, citric, and oxalic acids, were used with equal success When muriatic acid was used, the plates acquired the power of condensing the oxygen and hydrogen, but in a much inferior degree

586 Plates which were made positive in solution of caustic potassa did not show any sensible action upon the mixed oxygen and hydrogen Other plates made positive in solutions of carbonates of potassa and soda exhibited the action, but only in a feeble degree

587 When a neutral solution of sulphate of soda, or of nitre, or of chlorate of potassa, or of phosphate of potassa, or acetate of potassa, or sulphate of copper, was used, the plates, rendered positive in them for four minutes, and then washed in water, acted very readily and powerfully on the mixed oxygen and hydrogen

588 It became a very important point in reference to the cause of this action of the platina, to determine whether the positive pole only could confer it (567), or whether, notwithstanding the numerous contrary cases the negative pole might not have the power when such circumstances as could interfere with or prevent the action were avoided Three plates were therefore rendered negative, for four minutes in diluted sulphuric acid of specific gravity 1 336, washed in distilled water and put into mixed oxygen and hydrogen *All* of them *acted*, though not so strongly as they would have done if they had been rendered positive Each combined about a cubical inch and a quarter of the gases in twenty five minutes On every repetition of the experiment the same result was obtained and when the plates were retained in distilled water for ten or twelve minutes, before being introduced into the gas (582), the action was very much quickened

589 But when there was any metallic or other substance present in the acid which could be precipitated on the negative plate, then that plate ceased to act upon the mixed oxygen and hydrogen

590 These experiments led to the expectation that the power of causing oxygen and hydrogen to combine, which could be conferred upon any piece of platina by making it the positive pole of a voltaic pile, was not essentially dependent upon the action of the pile, or upon any structure or arrangement of parts it might receive whilst in association with it, but belonged to the platina *at all times*, and was *always effective* when the surface was *perfectly clean* And though when made the positive pole of the pile in acids, the circumstances might well be considered as those which would clean e the surface of the platina in the most effectual manner, it did not seem impossible that ordinary operations should produce the same result, although in a less eminent degree

591 Accordingly a platina plate (569) was cleaned by being rubbed with a cork a little water and some coal fire ashes upon a glass plate being washed, it was put into mixed oxygen and hydrogen, and was found to act at first slowly, and then more rapidly In an hour, a cubical inch and a half had disappeared

592 Other plates were cleaned with ordinary sand paper and water others with chalk and water others with emery and water, others again, with black oxide of manganese and water and others with a piece of charcoal and water All of these acted in tubes of oxygen and hydrogen causing combination of the gases The action was by no means so powerful as that produced by plates having been in communication with the battery, but from one to two cubical inches of the gases disappeared, in periods extending from twenty five to eighty or ninety minutes

593 Upon cleaning the plates with a cork ground emery, and dilute sulphuric acid, they were found to act still better In order to simplify the conditions, the cork was dismissed and a piece of platina foil used instead, still the effect took place Then the acid was dismissed and a solution of potassa used, but the effect occurred as before

594 These results are abundantly sufficient to show that the mere mechanical cleansing of the surface of the platina is sufficient to enable it to exert its combining power over oxygen and hydrogen at common temperatures

595 I now tried the effect of heat in conferring this property upon platina (584) Plates which had no action on the mixture of oxygen and hydrogen were heated by the flame of a freshly trimmed spirit-lamp, urged by a mouth blow pipe, and when cold were put into tubes of the mixed gases they acted slowly at first, but after two or three hours condensed nearly all the gases

596 A plate of platina which was about one inch wide and two and three-quarters in length and which had not been used in any of the preceding experiments was curved a little so as to

from the gas through the water heated red hot by the spirit-lamp and blowpipe and then returned when cold into the *same* portion of gas In the course of a few minutes diminution of the gases could be observed and in forty five minutes about one cubical inch and a quarter had disappeared In many other experiments platina plates when heated were found to acquire the power of combining oxygen and hydrogen

though often diminishing the power given to the plates at the positive pole of the pile (584) still it is evident that heat can render platina

pipe becomes dulled and clouded on its surface by something either formed or deposited there and this and much less than this is sufficient to prevent it from exhibiting the curious power now under consideration (634 636) Platina also has been said to combine with carbon and it is not at all unlikely that in processes of heating where carbon or its compounds are present a film of such a compound may be thus formed and thus prevent the exhibition of the properties belonging to *pure* platina [1]

[1] When heat does confer the property it is only by the destruction or dissipation of organic or other matter which had previously soiled the plate (633 634) —*Dec* 1838

and then put into the gases were found occasionally to act pretty well but at other times to fail In the latter case I concluded that the impurity upon the surface of the platina was of a nature not to be removed by the mere solvent action of the alkali for when the plates were

stant and satisfactory A platina plate was

the space of eight or nine minutes and rendering the tube warm (570)

trized in alkali or after other treatment were found inert immediately received power by being dipped for a minute or two or even only for an instant into hot oil of vitriol and then into water

603 When the plate was dipped into the oil of vitriol taken out and then heated so as to drive off the acid it did not act in consequence of the impurity left by the acid upon its surface

spirit-lamp flame and when hot rubbed with a piece of *potassa fusa* (caustic potash) which

put into water for four or five minutes to wash *off the alkali, shaken, and immersed for about* a minute in hot strong oil of vitriol, from this it was removed into distilled water, where it was allowed to remain ten or fifteen minutes to remove the last traces of acid (582) Being then put into a mixture of oxygen and hydrogen, combination immediately began, and proceeded rapidly, the tube became warm, the platina became red hot, and the residue of the gases was inflamed This effect could be repeated at pleasure, and thus the maximum phenomenon could be produced without the aid of the voltaic battery

606 When a solution of tartaric or acetic acid was substituted, in this mode of preparation, *for the sulphuric acid, still* the plate was found to acquire the same power, and would often produce explosion in the mixed gases, but the strong sulphuric acid was most certain and powerful

607 If borax, or a mixture of the carbonates

experimented with Gold and palladium exhibited the power either when made the positive

could not be made to show any effect at common temperatures

609 There can remain no doubt that the *property of* inducing combination, which can

spongy platina, and which was afterwards so well experimented upon and illustrated by MM Dulong and Thenard,[3] in 1823 The latter philosophers even quote experiments in which a very fine platina wire, which had been

duce at pleasure with either wires or plates by the processes described (570, 601, 605), and by using a smaller plate cut so that it shall rest against the glass by a few points, and yet allow the water to flow off (Pl VI, *Fig 4*), the loss of heat is less, the metal is assimilated somewhat to the spongy state, and the probability of failure almost entirely removed

610 M Dobereiner refers the effect *entirely* to an electric action He considers the platina

pers by MM Dulong and Thenard,[6] those philosophers show that elevation of temperature favours the action, but does not *alter its character*, Sir Humphry Davy's incandescent platina wire being the same phenomenon with Dobereiner's spongy platina They show that *all* metals have this power in a greater or smaller *degree, and that it is even possessed by* such bodies as charcoal, pumice, porcelain, glass, rock crystal, &c , when their temperatures are raised, and that another of Davy's effects, in which oxygen and hydrogen had combined *slowly together at a heat below* ignition, was really dependent upon the property of the heated glass, which it has in common with the bodies named above They state that liquids do not show this effect, at least that mercury, at *or below the boiling point*, has not the power, that it is not due to porosity, that the same body varies very much in its action according

with the acid evolved during ... from the heat itself to which it is then submitted

612 MM Dulong and Thenard express *them*selves with great caution on the theory of this

[1] The heat need not be raised so much as to make the alkali tarnish the platina, although if that effect does take place it does not prevent the ultimate action

[2] *Annales de Chimie* Vol XXIV, p 93

[3] *Ibid*, Vol XXIII p 440 Vol XXIV p 380.

[4] *Ibid* Vol XXIV, p 383

[5] *Ibid* Vol XXIV pp 91 95 Also *Bibliothèque Universelle* Vol XXIV p 54

[6] *Ibid*, Vol XXIII p 440 Vol *XXIV*, p 380.

action, but, referring to the decomposing power of metals on ammonia when heated to temperatures not sufficient alone to affect the alkali, *they remark that those metals which in* this case are most efficacious, are the least so in causing the combination of oxygen and hydrogen, whilst platina, gold, &c, which have least power of decomposing ammonia, have most power of combining the elements of water from which they are led to believe, that amongst gases, some tend to *unite* under the influence of metals, whilst others tend to *separate*, and that this property varies in opposite directions with the different metals At the close of their second paper they observe, that

that the greater number of the results observed by them are inexplicable, by supposing them to be of a purely electric origin

613 Dr Fusinieri has also written on this subject, and given a theory which he considers as sufficient to account for the phenomena [1] He expresses the immediate cause thus "The platina determines upon its surface a continual renovation of *concrete laminæ* of the combustible substance of the gases or vapours, which flowing over it are burnt, pass away, and are renewed this combustion at the surface raises and sustains the temperature of the metal" The combustible substance, thus reduced into imperceptible laminæ, of which the concrete parts are in contact with the oxygen, is presumed to be in a state combinable with the oxygen at a much lower temperature than when it is in the gaseous state, and more in analogy with what is called the nascent condition That

conclusion against all opposition of reasoning

614 The power or force which makes combustible gas or vapour abandon its elastic state in contact with a solid, that it may cover the latter with a thin stratum of its own proper substance, is considered as being neither attraction nor affinity It is able also to extend liquids and solids in concrete laminæ over the *surface of the acting solid body*, and consists in a *repulsion*, which is developed from the parts of the solid body by the simple fact of

sions of the attenuated mass decrease, and then in the direction of the angles or corners which from any cause may exist on the surface This force not only causes spontaneous diffusion of gases and other substances over the surface, but is considered as very elementary in its nature, and competent to account for all the phenomena of capillarity, chemical affinity, attraction of aggregation, rarefaction, ebullition, volatilization, explosion, and other thermometric effects, as well as inflammation, detonation, &c, &c It is considered as a form of heat to which the term *native caloric* is given, and is still further viewed as the principle of the two electricities and the two magnetisms

615 I have been the more anxious to give a correct abstract of Dr Fusinieri's view, both because I cannot form a distinct idea of the

616 Not feeling, however, that the problem has yet been solved, I venture to give the view

with regard to platina, it cannot be due to any peculiar, temporary condition, either of an electric or of any other nature the activity of plates rendered either positive or negative by the pole, or cleaned with such different substances as acids, alkalies, or water, charcoal, emery, ashes, or glass, or merely heated, is sufficient to negative such an opinion Neither

[1] *Giornale di Fisica, &c*, 1825 Vol VIII, p 259
[2] pp. 138, 371

much affect the rapidity, and therefore the visible appearances and secondary effects, of the action, i e, *the ignition of the metal and the inflammation of the gases*, they, even in their most favourable state, cannot produce any effect unless the condition of a clea[illegible] tallic surface be [illegible]

618 [illegible]
if not [illegible]
of the [illegible]
Dulon [illegible]
extend [illegible] the property to its possess[illegible] by all the metals, and by earths, glass, stones, &c (611), and every idea of its being a known and recognised electric action is in this way removed.

619 All the phenomena connected with this *subject press upon my mind the conviction* that the effects in question are entirely incidental and of a secondary nature that they are dependent upon the *natural conditions* of gaseous elasticity, combined with the exertion of that attractive force possessed by many bodies, especially those which are solid, in an eminent degree, and probably belonging to all by which they are drawn into asso[illegible]
less close, with [illegible]
chemical c[illegible]
the conditi[illegible]
ally leads, u[illegible]
as in *the pr*[illegible]
of bodies su[illegible] subjected to this *attraction I am prepared myself to admit (and* probably many others are of the same opinion), both with respect to the attraction of aggregation and of chemical affinity, that the sphere of action of particles extends beyond those other particles with which they are immediately and evidently in union (523), and in many cases produces effects rising into considerable importance and I think that this kind of attraction is a determining cause of Dobereiner's effect, and of the many others of a similar nature

620 *Bodies which become wetted by fluids* with which they do not combine chemically, or *in which they do not dissolve*, are simple and well known instances of this kind of attraction

621 All those cases of bodies which being insoluble in water and not combining with it are hygrometric, and condense its vapour around or upon their surface, are stronger instances of the same power, and approach a little nearer to the cases under investigation If pulverized clay, protoxide or peroxide of iron, oxide of manganese, charcoal, or even metals, as spongy platina or precipitated silver, be put into an atmosphere containing vapour of water they soon become moist by virtue of an attraction which *is able to condense the vapour upon* although not to combine it with, the substances and if as is well known, these bodies so damped be put into a dry atmosphere, as, for instance, one confined over sulphuric acid, or if they be heated, then they yield up this water again almost entirely, it not being in direct or permanent combination[1]

622 Still better instances of the power I refer to, because they are more analogous to the cases to be explained, are furnished by the attraction existing between glass and air, so well known to barometer and thermometer makers for here the adhesion or attraction is exerted between a solid and gases, bodies having very *different physical conditions, having* no power of combination with each other, and each *retaining, during the time of action, its* physical state unchanged[2] When mercury is poured into a barometer tube, a film of air will remain between the metal and glass for months or, as far as is known, for years, for it has never been displaced except by the action of means especially fitted for the purpose These consist in boiling the mercury, or in other words, of forming an abundance of vapour, which coming in contact with every part of the glass and every portion of surface of the mercury, gradually mingles with, *dilutes*, and carries off the air attracted by, and adhering to, those surfaces *replacing it by other vapour, subject* to an equal or perhaps greater attraction, but which when cooled condenses into the same liquid as that with which the tube is filled

623 Extraneous bodies, which, acting as nuclei in crystallizing or depositing solutions cause deposition of substances on them, when it does not occur elsewhere in the liquid, seem *to produce* their effects by a power of the same kind, i e, a power of attraction *extending* to neighbouring particles, and causing them to *become attached to the nuclei, although* it is not strong enough to make them combine chemically with their substance

624 It would appear from many cases of nuclei in solutions, and from the effects of bodies

[1] I met at Edinburgh with a [illegible] its extent, of h[illegible] [illegible]

put into atmospheres containing the vapours of water, or camphor, or iodine, &c, as if this attraction were in part elective, partaking in its characters both of the attraction of aggregation and chemical affinity nor is this inconsistent with, but agreeable to, the idea entertained that it is the power of particles acting, not upon others with which they can immediately and intimately combine, but upon such as are either more distantly situated with respect to them, or which, from previous condition, physical constitution, or feeble relation are unable to enter into decided union with them

625 Then, of all bodies, the gases are those which might be expected to show some *mutual* action whilst *jointly* under the attractive influence of the platina or other solid acting substance Liquids, such as water, alcohol, &c, are in so dense and comparatively incompressible a state, as to favour no expectation that their particles should approach much closer to each other by the attraction of the body to which they adhere, and yet that attraction must (according to its effects) place their particles as near to those of the solid wetted body as they are to each other, and in many cases it is evident that the former attraction is the stronger But gases and vapours are bodies competent to suffer very great changes in the relative distances of their particles by external agencies and where they are in immediate contact with the platina the approximation of the particles to those of the metal may be very great In the case of the hygrometric bodies referred to (621), it is sufficient to reduce the vapour to the fluid state frequently from atmospheres so rare that without this influence it would be needful to compress them by mechanical force into a bulk not more than 1/10th or even 1/40th of their original volume before the vapours would become liquids

626 Another most important consideration in relation to this action of bodies and which, as far as I am aware, has not hitherto been noticed, is the condition of elasticity under which the gases are placed against the acting surface We have but very imperfect notions of the real and intimate conditions of the particles of a body existing in the solid, the liquid, and the gaseous state, but when we speak of the gaseous state as being due to the mutual repulsions of the particles or of their atmospheres, although we may err in imagining each particle to be a little nucleus to an atmosphere of heat, or electricity, or any other agent we are still not likely to be in error in considering the elasticity as dependent on *mutuality* of action Now this mutual relation fails altogether on the side of the gaseous particles next to the platina, and we might be led to expect *à priori* a deficiency of elastic force there to at least one half, for if, as Dalton has shown, the elastic force of the particles of one gas cannot act against the elastic force of the particles of another, the two being as vacua to [illegible] is it far [illegible] ina car [illegible] against [illegible] particle [illegible]

627 But the diminution of power to one-half on the side of the gaseous body towards the metal is only a slight result of what seems to me to flow as a necessary consequence of the known constitution of gases An atmosphere of one gas or vapour, however dense or compressed, is in effect as a vacuum to another thus if a little water were put into a vessel containing a dry gas, as air, of the pressure of one hundred atmospheres, as much vapour of the water would *rise* as if it were in a perfect vacuum Here the particles of watery vapour appear to have no difficulty in [illegible] [illegible] [illegible] [illegible] [illegible] as itself how much more surely must it be so with particles like those of the platina or other limiting body, which at the same time that they have not these elastic powers, are also unlike it in nature! Hence it would seem to result that the particles of hydrogen or any other gas or vapour which are next to the platina &c, must be in such contact with it as if they were in the liquid state, and therefore almost infinitely closer to it than they are to each other, even though the metal be supposed to exert no attractive influence over them

628 A third and very important consideration in favour of the mutual action of gases under these circumstances is their perfect miscibility If fluid bodies capable of combining together are also capable of mixture, *they do combine* when they are mingled, not waiting for any other determining [illegible] suc[illegible] getl[illegible] pon[illegible] thou[illegible] [illegible]stances, they do not combine by mere mixture Still it is evident that, from their perfect association, the particles are in the most favourable state

for combination upon the supervention of any determining cause, such either as the negative action of the platina in suppressing or annihilating, as it were, their elasticity on its side, or the *positive action of the metal in condensing* them against its surface by an attractive force, or the influence of both together

629 Although there are not many distinct cases of combination under the influence of *forces external to the combining particles, yet there are sufficient to remove any difficulty* which might arise on that ground Sir James Hall found carbonic acid and lime to remain combined under pressure at temperatures at which *they would not have remained combined* if the *pressure had been removed*, and I have had occasion to observe a case of direct combination in chlorine,[1] which being compressed at common temperatures will combine with water, and *form a definite crystalline hydrate, incapable either of being formed or of existing* if that pressure be removed

630 The course of events when platina acts upon, and combines oxygen and hydrogen, may *be stated, according to these principles, as follows* From the influence *of the circumstances* mentioned (619, &c), i e, the deficiency of elastic power and the attraction of the metal for the gases, the latter, when they are in as*sociation with the former, are so far condensed* as to be brought within the action of their mutual affinities at the existing temperature, the deficiency of elastic power, not merely subjecting them more closely to the attractive influ*ence of the metal but also bringing them into* a more favourable state for union, by abstracting a part of that power (upon which depends their elasticity) which elsewhere in the mass of gases is opposing *their combination* The consequence of their *combination is the production* of the vapour of water and an elevation of temperature But as the attraction of *the platina for the water formed is not greater* than *for the gases, if so great* (for the *metal is* scarcely hygrometric), the vapour is quickly diffused through the remaining gases fresh portions of the latter, therefore, come into juxtaposition with the metal, combine, and the *fresh vapour formed is also diffused, allowing* new portions of gas to be acted upon In th s way the process adv... by th...
pe...
pe...
th...
... ...

631 The dissipation of the *vapour produced* at the surface of the platina, and the contact of fresh oxygen and hydrogen with the metal, form no difficulty in this explication The platina is not considered as causing the combination of any particles with *itself, but only associat*ing them closely around it and the compressed particles are as free to move from the platina being replaced by other particles as a portion of dense air upon the surface of the globe, *or at the bottom of a deep mine, is free to move* by the slightest impulse, into the upper and rarer parts of the atmosphere

632 It can hardly be necessary to give any reasons why platina does not show this effect *under ordinary circumstances It is then not* sufficiently clean (617), and the gases are prevented from touching it, and suffering that degree of effect which is needful to commence their combination at common temperatures and *which they can only experience* at its surface In fact, the very power which causes the combination of oxygen and hydrogen is competent, under the usual casual exposure of platina, *to condense extraneous matters upon its surface, which, soiling it, take* away for the time its power of combining oxygen and hydrogen, by preventing their contact with it (598)

633 *Clean platina*, by which *I mean* such as has been made the positive pole of a pile (570), or has been treated with acid (605), and has then been put into distilled water for twelve or fifteen minutes, has a *peculiar friction* when *one piece is rubbed against another* It wets freely with pure water, even after it has been shaken and dried by the heat of a spirit-lamp, and if made the pole of a voltaic pile in a *dilute* acid, it evolves minute *bubbles from every part of its surface* But platina in its common state wants that peculiar friction it will not wet freely with water as the clean platina does and *when made the positive pole of a pile, it* for a time *gives off large bubbles*, which seem to cling or adhere to the metal, and are evolved at distinct and separate points of the surface These appearances and effects, as well as its want of power on oxygen and *hydrogen* are the consequences, and the indications, of a soiled surface

634 I found also that platina *plates which had been cleaned perfectly soon became soiled by mere exposure to the air* for after twenty-four hours they no longer moistened freely with water, but the fluid ran up into portions, leaving part of the surface bare, whilst *other plates*

which had been retained in water for the same time, when they were dried (580) did moisten, and gave the other indications of a clean surface.

635 Nor was this the case with platina or metals only, but also with earthy bodies Rock crystal and obsidian would not wet freely upon the surface, but being moistened with strong oil of vitriol, then washed, and left in distilled water to remove all the acid, they did freely become moistened whether they were previously dry or whether they were left wet, but being dried and left exposed to the air for twenty four hours, their surface became so soiled that water would not then adhere freely to it but ran up into partial portions Wiping with a cloth (even the cleanest) was still worse than exposure to air, the surface either of the minerals or metals immediately became as if it were slightly greasy The floating upon water of small particles of metals under ordinary circumstances is a consequence of this kind of soiled surface The extreme difficulty of cleaning the surface of mercury when it has once been soiled or greased is due to the same cause

636 The same reasons explain why the pow

the surface of the platina is retained there and is sufficient to prevent its full action upon oxygen and hydrogen at common temperatures a slight elevation of temperature is again sufficient to compensate this effect, and cause combination

637 No state of a solid body can be conceived more favourable for the production of the effect than that which is possessed by platina obtained from the ammonio-muriate by heat Its

is evolved by the combination of the first portions of gas is retained within the mass, exalt-

ing the tendency of the succeeding portions to combine

638 I have now to notice some very extraordinary interferences with this phenomenon, dependent, not upon the nature or condition of the metal or other acting solid but upon the presence of certain substances mingled with the gases acted upon and as I shall have occasion to speak frequently of a mixture of oxygen and hydrogen, I wish it always to be understood that I mean a mixture composed of one volume of oxygen to two volumes of hydrogen, being the proportions that form water Unless otherwise expressed, the hydrogen was always that obtained by the action of dilute sulphuric acid on pure zinc and the oxygen that obtained by the action of heat from the chlorate of potassa

639 Mixtures of oxygen and hydrogen with air, containing one-fourth, one-half and even two-thirds of the latter being introduced with

gases with the plates In two hours and a half nearly all the oxygen and hydrogen introduced as mixture was gone

ture of 3 volumes oxygen and one volume ole-

ly sensible at the end of two hours during which it was watched but on exami twenty four hours afterwards, the

[1] *Annales de Chimie* Vol. XXIV p 386

found blown to pieces The action, therefore, though it had been very much retarded, had occurred at last, and risen to a maximum

642 With a mixture of ninety nine volumes of oxygen and hydrogen (638) with one of olefiant gas, a feeble action was evident at the end of fifty minutes it went on accelerating (630) until the eighty fifth minute, and then became so intense that the gas exploded Here also the retarding effect of the olefiant gas was very beautifully illustrated

643 Plates prepared by alkali and acid (605) produced effects corresponding to those just described

644 *It is perfectly clear from these experiments*, that *olefiant gas*, even in small quantities, has a very remarkable influence in preventing the combination of oxygen and hydrogen under these circumstances, and yet without at all injuring or affecting the power of the platina

645 Another striking illustration of similar interference may be shown in *carbonic oxide*, especially if contrasted with *carbonic acid* A mixture of one volume oxygen and hydrogen (638) with four volumes of carbonic acid was affected at once by a platina plate prepared with acid, &c (605), and in one hour and a quarter nearly all the oxygen and hydrogen was gone Mixtures containing less carbonic acid were still more readily affected

646 But when carbonic oxide was substituted for the carbonic acid, not the slightest effect of combination was produced, and when the carbonic oxide was only one-eighth of the whole volume, no action occurred in forty and fifty hours Yet the plates had not lost their power for being taken out and put into pure oxygen and hydrogen, they acted well and at once

647 Two volumes of carbonic oxide and one of oxygen were mingled with nine volumes of oxygen and hydrogen (638) This mixture was not affected by a plate which had been made positive in acid, though it remained in it fifteen hours But when to the same volumes of carbonic oxide and oxygen were added thirty-three volumes of oxygen and *hydrogen*, the carbonic oxide being then only 1/18th part of the whole, the plate acted, slowly at first, and at the end of forty two minutes the gases exploded

648 These experiments were extended to various gases and vapours, the general results of which may be given as follow Oxygen, *hydrogen*, nitrogen, and nitrous oxide, when used to dilute the mixture of oxygen and hydrogen, did not prevent the action of the plates even when they made four-fifths of the whole volume of gas acted upon Nor was the retardation so great in any case as might have been expected from the mere dilution of the oxygen and hydrogen, and the consequent mechanical obstruction to its contact with the platina The order in which carbonic acid and these substances seemed to stand was as follows, the first interfering least with the action, *nitrous oxide, hydrogen, carbonic acid, nitrogen, oxygen* but it is possible the plates were not equally well prepared in all the cases, and that other circumstances also were unequal consequently *more numerous experiments would be required to* establish the order accurately

649 As to cases of *retardation*, the powers of olefiant gas and carbonic oxide have been already described Mixtures of oxygen and hydrogen, containing from 1/60th, to 1/30th of sulphuretted hydrogen or phosphuretted hydrogen, seemed to show a little action at first, but were not further affected by the prepared plates though in contact with them for seventy hours When the plates were removed they had lost all power over pure oxygen and *hydrogen*, and the interference of these gases was therefore of a different nature from that of the two former having permanently affected the plate

650 A small piece of cork was dipped in sulphuret of carbon and passed up through water into a tube containing oxygen and hydrogen (638), so as to diffuse a portion of its vapour through the gases A plate being introduced appeared at first to act a little, but after sixty one hours the diminution was very small Upon putting the same plate into a *pure* mixture of oxygen and hydrogen, it acted at once and powerfully, having apparently suffered no diminution of its force

651 A little vapour of ether being mixed with the oxygen and hydrogen retarded the action of the plate, but did not prevent it altogether A little of the vapour of the condensed oil gas liquor[1] retarded the action still more but not nearly so much as an equal volume of olefiant gas would have done In both these cases it was *the original oxygen* and hydrogen which combined together, the ether and the oil-gas vapour remaining unaffected, and in both cases the plates retained the power of acting on fresh oxygen and hydrogen

652 Spongy platina was then used in place of the plates, and jets of hydrogen mingled with the different gases thrown against it in

[1] *Philosophical Transactions* 1825 p. 440.

air The results were exactly of the same kind, although presented occasionally in a more imposing form

the experiments were commenced at common temperatures, but a mixture of equal volumes of nitrogen and hydrogen acted very well, causing ignition With carbonic acid the results were still more striking A mixture of three volumes of that gas with one of hydrogen caused *ignition* of the platina, yet that mixture would not continue to burn from the jet when attempts were made

can do nothing with the platina, are *inflamed* by the taper, burning well

in proportion merely to the quantity of carbon present

654 In connexion with the

platina It had stood over water seven days,

the influence of a prepared plate or of spongy platina. A mixture of one volume of this gas with three of pure hydrogen, and the due proportion of oxygen, was not affected by plates after fifty hours I am inclined to refer the effect to carbonic oxide present in the gas, but have not had time to verify the suspicion The power of the plates was not destroyed (640, 646).

655 Such are the general facts of these remarkable

may exert upon the particles of oxygen and hydrogen, by which the Lat

extended experiments.

656 The theory of action which I have given for the original phenomena appears to me quite sufficient to account for all the effects by reference

one of great consequence, because I am convinced that the superficial actions of matter, whether between two bodies, or of one piece of the same body, and the actions of particles not directly or strongly in combination, are becoming daily more and more important to our theories of chemical as well as

have great influence over the combinations there taking place

657 The condition of elasticity upon the exterior of the gaseous or vaporous mass already referred to (626, 627), must be connected directly with the action of solid bodies, as nuclei, on vapours, causing condensation upon them in preference to any condensation in the vapours themselves, and in the well-known effect of nuclei on solutions a similar condition may have existence (623), for an analogy in condition exists between the parts of a body in solution, and those of a body in the vaporous or gaseous state This thought leads us to the consideration of what are the respective conditions at the surfaces of contact of two portions of the same substance at the same temperature, one in the solid or liquid, and the other in the vaporous state, as, for instance,

steam and water It would seem that the par ticles of vapour next to the particles of liquid are in a different relation to the latter to what they would be with respect to any other liquid or sol d substance as for instance mercury or platina if they were made to replace the water i e if the view of independent action which I have taken (626 627) as a consequence of Dal ton s principles be correct It would also seem that the mutual relation of similar particles and the indifferenc of diss milar particles which Dalton has established as a matter of fact amongst gases and vapours extends to a certain degree amongst solids and fluids that is when they are in relation by contact with vapours either of their own substance or of other bod es But though I view these points as of

gaseous state I have not sufficiently considered them to venture any strong opinions or statements here[1]

658 There are numerous well known cases in which substances such as oxygen and hydrogen act readily in their *nascent* state and produce chemical changes which they are not able to effect if once they have assumed the

drogen are to each other on the surface of clean platina (626 627)

659 The s ngular effects of retardation produced by very small quantities of some gases

different gases when pass ng through narrow tubes at low pressures which I observed many

in which it has been experimented upon by Mr Graham in 1829 and 1831[2] and also by Dr Mitchell of Philadelphia[4] in 1830 It seems ve y

Paris

660 I intended to have followed this section by one on the secondary piles of Ritter and the pecul ar properties of the poles of the pile or of metals through which electricity has passed which have been observed by Ritter Van Marum Yelin De la Rive Marianini Berze- all these

gation just term nated and do not require the assumption of any new state or new property But as the experiments advanced especially those of Marianini require very careful repe-

Royal Institution November 30 1833

[1] *Quarte ly Journal of Science* 1819 Vol VII p 106

[2] *Quarterly Journal of Science* Vol XXVIII p 74, and *Ed nburgh Transactions* 1831

[4] *Journal of the Royal Inst tution* for 1831 p 101

SEVENTH SERIES

§ 11. *On Electro-chemical Decomposition, continued*[1] ¶ iv. *On Some General Conditions of Electro-chemical Decomposition* ¶ v. *On a New Measurer of Volta-electricity* ¶ vi. *On the Primary or Secondary Character of the Bodies Evolved at the Electrodes* ¶ vii. *On the Definite Nature and Extent of Electro-chemical Decompositions* § 13. *On the Absolute Quantity of Electricity Associated with the Particles or Atoms of Matter*

RECEIVED JANUARY 9, READ JANUARY 23, FEBRUARY 6 AND 13, 1834

Preliminary

661 THE theory which I believe to be a true expression of the facts of electro-chemical decomposition, and which I have therefore detailed in a former series of these *Researches*, is so much at variance with those previously advanced, that I find the greatest difficulty in stating results, as I think, correctly, whilst limited to the use of terms which are current with a certain accepted meaning Of this kind is the term *pole*, with its prefixes of positive and negative, and the attached ideas of attraction and repulsion The general phraseology is that the positive pole *attracts* oxygen, acids, &c , or more cautiously, that it *determines* their evolution upon its surface; and that the negative pole [illegible]

the oyxgen and acids are rendered at the *neg-* [illegible]

currence in framing them, I purpose henceforward using certain other terms, which I will now define. The *poles*, as they are usually called, are only the doors or ways by which the electric current passes into and out of the decomposing body (556); and they of course, when in contact with that body, are the limits of its extent in the direction of the current. The term has been generally applied to the metal surfaces in contact with the decomposing substance, but whether philosophers generally would also apply it to the surfaces of air (465, 471) and water (493), against which I have effected electro-chemical decomposition, is subject to doubt In place of the term pole, I propose using that of *electrode*,[2] and I mean thereby that substance, or rather surface, whether of air, water, metal, or any other body, which bounds the extent of the decomposing matter in the direction of the electric current.

663 The surfaces at which, according to common phraseology, the electric current enters and leaves a decomposing body, are most [illegible]

[1] Refer to the note after 1047, Series VIII —*Dec.* 1838

[2] ἤλεκτρον, and ὁδὸς 'a way.'

powers Upon this notion we purpose calling that towards the east the *anode*,[1] and that towards the west the *cathode*,[2] and whatever changes may take place in our views of the nature of electricity and electrical action, as they must affect the *natural standard* referred to, in the same direction, and to an equal amount with any decomposing substances to which these *terms* may at any time be applied, *there* seems no reason to expect that they will lead to *confusion, or tend in any way to support* false views The *anode* is therefore that surface at which *the electric current, according to our* present expression, enters it is the *negative* extremity *of the* decomposing body, is where oxygen, chlorine, acids, &c , are evolved and is against or *opposite* the positive electrode The *cathode* is that surface at which the current leaves the decomposing body, and is its *positive* extremity the combustible bodies metals, alkalies, and bases, are evolved there, and it is in contact with the negative electrode

664 *I shall* have occasion in these *Researches*, also, to class bodies together according to certain relations derived from their electrical actions (822), and wishing to express those relations without at the same time involving the expression of any hypothetical views, I intend using the following names and terms Many bodies are decomposed directly by the electric current, their elements being set free these I propose to call *electrolytes* [3] Water, therefore, is an electrolyte The bodies which, like nitric or sulphuric acids are decomposed in a secondary manner (752, 757), are not included under this term Then for *electro-chemically decomposed*, I shall often use the term *electrolyzed*, derived in the same way, and implying that the body spoken of is separated into its components under the influence of electricity it is analogous in its sense and sound to *analyze*, which is derived in a similar manner The term *electrolytical* will be understood at once, muriatic acid is electrolytical, boracic acid is not

665 Finally, I require a term to express those bodies which can pass to the *electrodes*, or, as they are usually called, the poles Substances are frequently spoken of as being *electro-negative*, or *electro-positive*, according as they go under the supposed influence of a direct attraction to the positive or negative pole But these terms are much too significant for the use to which I should have to put them, for though the meanings are perhaps right, *they are only* hypothetical, and may be wrong, and then, through a very *imperceptible, but still very* dangerous, because continual, influence *they do great injury to science, by contracting and* limiting the habitual views of those engaged in *pursuing it I propose to distinguish such bodies* by calling those *anions*[4] which go to the *anode of* the decomposing body, *and those passing* to the *cathode, cations*,[5] and when I have *occasion* to speak of *these together, I shall call* them *ions* Thus the chloride of lead is an *electrolyte*, and when *electrolyzed evolves the two ions*, chlorine and lead, the former being an *anion*, and the latter a *cation*

666 These terms being once well-defined will, I hope, in their use enable me *to avoid* much periphrasis and ambiguity of expression I do not mean to press them into *service more* frequently than will be required, for I am *fully* aware that names are one thing and *science* another

667 It will be well understood that I am gi[ving] no opinion respecting the nature of the elec[tric] current now, beyond what *I have done* o[n] former occasions (283, 517), and that though [I] speak of the current as proceeding *from th[e]* parts which are positive to those which are neg[ative] (663), it is merely in accordance with th[e] conventional, though in some degree tacit agreement entered into by scientific men, *tha[t]* they *may* have a constant, certain, and definit[e] means of referring to the direction of *the force[s]* of that current [6]

¶ iv *On Some General Conditions of Electro-chemical Decomposition*

669 From the period when electro-chemical decomposition was first effected to the *present* time, it has been a remark, that those elements which, in *the ordinary* phenomena *of chemical* affinity, were the most directly opposed *to each* other, and combined with *the greatest* attractive force, were those which were the most readily evolved at the opposite *extremities* of the decomposing bodies (549)

670 *If* this result was evident *when water* was supposed to be essential to, and was pre-

[1] ἄνω upwards' and ὁδός a way,' the way which the *sun* rises

[2] κατά 'downwards', and ὁδός 'a way', the way which the *sun sets*.

[3] ἤλεκτρον and λύω *solvo* N Electrolyte V Electrolyze.

[4] ἀνιόν that which goes up ' (Neuter participle)

[5] κατιόν that which goes down.'

[6] Since this paper was read I have changed some of the terms which were first proposed that I might employ only such as were at the same time *simple* in their nature clear *in* their reference and *free from* hypothesis.

ent in, almost every case of such decomposition (472), it is far more evident now that it has been shown and proved that water is not necessarily concerned in the phenomena (474), and that other bodies much surpass it in some of the effects supposed to be peculiar to that substance

pound formed by

yields up its elements under the influence of a very feeble electric current, and it is doubtful whether a case of electrolyzation can occur, where, being present, it is not resolved into its first principles

672 The various oxides, chlorides, iodides, and salts, which I have shown are decomposable by the electric current when in the liquid state under the same general law with water

opposed, be operated upon, it suffers composition, and if borate of lead glass, which is a definite chemical compound, be experimented with, it readily yields up its elements (408)

674 But the result which is found to be so striking in the instances quoted is not at all

[1] *Philosophical Transactions* 1830 p 49

ture of chemical affinity and the mode of action of an electric current over it (518, 524) besides which, it is just as directly opposed to any other theory of electro-chemical decomposition as the one I have propounded, for if it be admitted, as is generally the case, that the more directly bodies are opposed to each other in their

which have been considered,

to those which I have taken against them

675 Amongst powerful compounds which

of

must by comparison be very ion takes place[2]

676 It must not be forgotten, however, that much of this difficulty, and perhaps the whole, may depend upon the absence of conducting power, which, preventing the transmission of the current, prevents of course the effects due to it All known compounds being non-conductors when solid, but conductors when li- the single

if rendered

want of decomposition in the it might be so

solution I have met

powers Upon this notion we purpose calling that towards the east the *anode*,[1] and that towards the west the *cathode*,[2] and whatever changes may take place in our views of the nature of electricity and electrical action, as they must affect the *natural standard* referred to, in the same direction, and to an equal amount with any decomposing substances to which these terms may at any time be applied, there seems no reason to expect that they will lead to confusion, or tend in any way to support false views The *anode* is therefore that surface at which the electric current, according to our present expression, enters it is the *negative* extremity of the decomposing body, is where oxygen, chlorine, acids, &c., are evolved, and is against or opposite the positive electrode. The *cathode* is that surface at which the current leaves the decomposing body, and is its *positive* extremity, the combustible bodies, metals, alkalies, and bases, are evolved there, and it is in contact with the negative electrode

664 I shall have occasion in these *Researches*, also, to class bodies together according to certain relations derived from their electrical actions (822), and wishing to express those relations without at the same time involving the expression of any hypothetical views, I intend using the following names and terms Many bodies are decomposed directly by the electric current, their elements being set free, these I propose to call *electrolytes*.[3] Water, therefore, is an electrolyte The bodies which, like nitric or sulphuric acids are decomposed in a secondary manner (752, 757), are not included under this term Then for *electro-chemically decomposed*, I shall often use the term *electrolyzed*, derived in the same way, and implying that the body spoken of is separated into its components under the influence of electricity it is analogous in its sense and sound to *analyze*, which is derived in a similar manner The term *electrolytical* will be understood at once muriatic acid is electrolytical, boracic acid is not

665. Finally, I require a term to express those bodies which can pass to the *electrodes*, or, as they are usually called, the poles Substances are frequently spoken of as being *electro-negative*, or *electro-positive*, according as they go under the supposed influence of a direct attraction to the positive or negative pole But these terms are much too significant for the use to which I should have to put them, for though the meanings are perhaps right, they are only hypothetical, and may be wrong; and then, through a very imperceptible, but still very dangerous, because continual, influence, they do great injury to science, by contracting and limiting the habitual views of those engaged in pursuing it I propose to distinguish such bodies by calling those *anions*[4] which go to the *anode* of the decomposing body, and those passing to the *cathode*, *cations*[5] and when I have occasion to speak of these together, I shall call them *ions* Thus the chloride of lead is an *electrolyte*, and when *electrolyzed* evolves the two *ions*, chlorine and lead, the former being an *anion*, and the latter a *cation*

666 These terms being once well-defined will, I hope, in their use enable me to avoid much periphrasis and ambiguity of expression. I do not mean to press them into service more frequently than will be required, for I am fully aware that names are one thing and science another

667 It will be well understood that I am giving no opinion respecting the nature of the electric current now, beyond what I have done on former occasions (283, 517), and that though I speak of the current as proceeding from the parts which are positive to those which are negative (663), it is merely in accordance with the conventional, though in some degree tacit, agreement entered into by scientific men that they may have a constant certain, and definite means of referring to the direction of the forces of that current[6]

¶ IV *On Some General Conditions of Electro-chemical Decomposition*

669 From the period when electro-chemical decomposition was first effected to the present time, it has been a remark, that those elements which, in the ordinary phenomena of chemical affinity, were the most directly opposed to each other, and combined with the greatest attractive force, were those which were the most readily evolved at the opposite extremities of the decomposing bodies (549)

670 If this result was evident when water was supposed to be essential to, and was pres-

[1] ἄνω 'upwards' and ὁδός 'a way' the way which the sun rises.

[2] κατά 'downwards', and ὁδός 'a way', the way which the sun sets

[3] ἤλεκτρον and λύω solvo N Electrolyte V Electrolyze

[4] ἀνιών 'that which goes up' (Neuter participle.)

[5] κατιών 'that which goes down'

[6] Since this paper was read I have changed some of the terms which were first proposed that I might employ only such as were at the same time simple in their nature clear in their reference and free from hypothesis.

686 That these mineral acids should confer facility of conduction and decomposition on water, is no proof that they are competent to favour and suffer these actions in themselves Boracic acid does the same thing, though not decomposable M de la Rive has pointed out that chlorine has this power also, but being to us an elementary substance, it cannot be due to its capability of suffering decomposition

687 *Chloride of sulphur* does not conduct, nor is it decomposed It consists of single proportionals of its elements, but is not on that account an exception to the rule (679), which does not affirm that *all* compounds of single proportionals of elements are decomposable, but that such as are decomposable are so constituted

688 *Protochloride of phosphorus* does not conduct nor become decomposed

689 *Protochloride of carbon* does not conduct nor suffer decomposition In association with

to conduct or yield up its elements

690 With regard to the exceptions (679), upon closer examination some of them disappear Chloride of antimony (a compound of one proportional of antimony and one and a half of chlorine) of recent preparation was put into a tube (Pl VI, *Fig 13*) (789), and submitted when fused to the action of the current, the positive electrode being of plumbago No electricity passed, and no appearance of decomposition was visible at first but when the positive and negative electrodes were brought very near each other in the chloride, then a feeble action occurred and a feeble current passed The effect altogether was so small (although quite amenable to the law before given (394)), and so unlike the decomposition and conduction occurring in all the other cases, that I attribute it to the presence of a minute quantity of water (for which this and many other chlorides have strong attractions, producing hydrated chlorides), or perhaps of a true protochloride consisting of single proportionals (695, 796)

691 *Periodide of mercury* being examined in the same

No iodine appeared at the *anode* nor mercury or other substance at the *cathode* The case is, therefore, no exception to the rule, that only

decomposition the feeble conducting power is due Periodide would be formed, as a secondary result, at the *anode* and the mercury at the *cathode* would also form, as a secondary result, protiodide Both these bodies would mingle with the fluid mass and thus no final separation appear, notwithstanding the continued decomposition

692 When *perchloride of mercury* was subjected to the voltaic current it did not conduct in the solid state, but it did conduct when fluid I think, also, that in the latter case it was decomposed but there are many interfering circumstances which require examination before a positive conclusion can be drawn [1]

693 When the ordinary protoxide of antimony is subjected to the voltaic current in a fused state, it also is decomposed, although the effect from other causes soon ceases (402, 801) This oxide consists of one proportional of anti-

often contain other compounds consisting of single proportions which are the true *proto* compounds, and which, in the case of the oxide might give rise to the decomposition above described

694 The ordinary sulphuret of antimony is considered as being the compound with the smallest quantity of sulphur, and analogous in its proportions to the ordinary protoxide But I find that if it be fused with metallic antimony, a new sulphuret is formed, containing much more of the metal than the former, and separating distinctly, when fused, both from the

[1] With regard to perchloride and periodide of mercury see now 1340 1341 —*Dec* 1838.

this seems to be very nearly decided On the other hand, the conclusion is almost irresistible that in electrolytes the power of transmitting the electricity across the substance is *dependent upon their capability of suffering decomposition*, taking place only whilst they are decomposing, and being proportionate to the quantity of elements separated (821) I may not, however stop to discuss this point experimentally at present

678 When a compound contains such elements *as are known to pass towards the opposite extremities of the voltaic pile*, still the *proportions in which they are present appear to be* intimately connected with capability in the compound of suffering or resisting decomposition Thus, the protochloride of tin readily conducts, and is decomposed (402), but the perchloride neither conducts nor is decomposed (406) The protiodide of tin is decomposed when fluid (402) the periodide is *not* (405) The periodide of mercury when fused is not decomposed (691), *even though it does conduct* I was unable to contrast it with the protiodide, the latter being converted into mercury and periodide by heat

679 These important differences induced me to look more closely to certain binary compounds, with a view of ascertaining whether a *law* regulating the *decomposability* according to some *relation of the proportionals or equivalents of the elements, could be discovered The proto* compounds only, amongst those just referred to, were decomposable and on referring to the substances quoted to illustrate the force and generality of the law of conduction and decomposition which I discovered (402), it will be found that all the oxides, chlorides, and iodides subject to it except the chloride of antimony and the periodide of mercury (to which may now *perhaps* be added corrosive sublimate), are also decomposable, whilst many *per compounds of the same elements, not subject to* the law, were not so (405, 406)

680 The substances which appeared *to form* the strongest exceptions to this general result were such bodies as the sulphuric, phosphoric, nitric, arsenic, and other acids

681 On experimenting with sulphuric acid, I found no reason to believe that it was by itself a conductor of, or decomposable by, electricity, although I had previously been of that opinion (552) When very strong it is a much *worse conductor* than if diluted [1]If then subjected to the action of a powerful battery, oxygen appears at the *anode*, or positive electrode although much is absorbed (728), and hydrogen and *sulphur appear at the cathode, or negative* electrode Now the hydrogen has with me *always* been *pure*, not *sulphuretted*, and has been deficient in proportion to the sulphur present, so that it is evident that when decomposition occurred water must have been decomposed I endeavoured to make the experiment with anhydrous sulphuric acid, and it appeared to me that, when fused, such acid was not a *conductor*, nor *decomposed*, but I had not enough of the dry acid in my possession to allow me to decide the point *satisfactorily* My belief is, that when sulphur appears during the action of the pile on sulphuric acid, *it is* the result of a secondary action, and that the acid itself is not electrolyzable (757)

682 Phosphoric acid is, I believe, also in the same condition, but I have found it impossible *to decide the point*, because of the difficulty of operating on fused anhydrous phosphoric acid *Phosphoric acid which has once obtained* water cannot be deprived of it by heat alone When heated, the hydrated acid *volatilises*. Upon subjecting phosphoric acid, fused upon the ring end of a wire (401), to the action of the voltaic apparatus, it conducted, and was decomposed, but gas, which I believe to be hydrogen, was always evolved at the negative electrode, and the wire was not affected as *would have happened had phosphorus* been separated Gas was also evolved at the positive electrode *From all the facts, I conclude* it was the water and not the acid which was decomposed

683 *Arsenic acid* This substance conducted and was decomposed but it contained *water*, and I was unable at the time to press the investigation so as to ascertain whether a *fusible* anhydrous arsenic acid could be obtained It forms, therefore, at present no exception *to the general result*

684 Nitrous acid, obtained by distilling *nitrate of lead, and keeping it* in contact with strong sulphuric acid, was found to conduct and decompose *slowly But on* examination there were strong reasons for believing that water was present, and that *the decomposition* and conduction depended upon it I endeavoured to prepare a *perfectly anhydrous* portion, but could not spare the time required to procure an unexceptionable result.

685 Nitric acid is a substance which I believe is not decomposed directly by *the electric* current. As I want the facts in illustration of

[1] De la Rive

salts its elements may in numerous cases be obtained and collected without any embarrassment from secondary action, and, being gaseous, they are in the best physical condition for separation and measurement Water, therefore, acidulated by sulphuric acid, is the substance I shall generally refer to, although it may become expedient in peculiar cases or forms of experiment to use other bodies (843)

707 The first precaution needful in the con-

as near to the mouths of the tubes as was consistent with the safe collection of the gases

near to each other, that as little decomposing matter should intervene as possible and also, in such a direction that the platina plates should be in vertical planes (720)

708 An ... that de-

tion, *b*, is introduced at the time decomposition is to be effected, being brought as near the angle as possible, without causing any gas to pass from it towards the closed end of the instrument The gas evolved against it is allowed to escape.

709 The third form of apparatus contains both electrodes in the same tube, the transmission, therefore, of the electricity, and the consequent decomposition, is far more rapid than in the separate tubes The resulting gas is the sum of the portions evolved at the two electrodes, and the instrument is better adapted than either of the former as a measurer of the quantity of voltaic electricity transmitted in ordinary cases It consists of a straight tube

whole, flow into the tube and fill it When an electric current is passed through the instrument, the gases evolved against the plates collect in the upper portion of the tube and are not subject to the recombining power of the platina

710 Another form of the instrument is given at Pl VI, *Fig* 10

711 A fifth form is delineated (Pl VI, *Fig* 11) This I have found exceedingly useful in

hermetically at the part held in the stand is five inches in length, and 0 6 of an inch in diameter the neck about nine inches in length, and 0 4 of an inch in diameter internally The figure will fully indicate the construction

712 It can hardly be requisite to remark, that in the arrangement of any of these forms

through the other

stances which would require to be practically guarded against

714 The first point investigated was the influence or indifference of extensive variations in the size of the electrodes, for which purpose instruments like those last described (709, 710, 711) were used One of these had plates 0 7 of an inch wide, and nearly four inches long, another had plates only 0.5 of an inch wide, and 0 8 of an inch long, a third had wires 0 02 of an inch in diameter, and three inches long, and a fourth, similar wires only half an inch in length Yet when these were filled with dilute sulphuric acid, and, being placed in succession, had one common current of electricity passed through them, very nearly the same quantity of gas was evolved in all The difference was sometimes in favour of one and sometimes on the side of another, but the general result was that the largest quantity of gases was evolved at the smallest electrodes, namely, those consisting *merely of platina wires*

715 Experiments of a similar kind were made with the single-plate, straight tubes (707), and also with the curved tubes (708), with similar consequences, and when these, with the former tubes, were arranged together in various ways, the result, as to the equality of action of large and small metallic surfaces when delivering and receiving the same current of electricity, *was constantly the same As an illustration*, the following numbers are given An instrument *with two wires* evolved 74.3 *volumes* of mixed gases, another with plates 73 25 volumes whilst the sum of the oxygen and hydrogen in two separate tubes amounted to 73 65 volumes In another experiment the volumes were 55 3, 55.3, and 54 4

716 But it was observed in these experiments, that in single-plate t b hydrogen ... than ... at the positi ... generally, also, more than was proportionate to the oxygen and hydrogen in a double-plate tube Upon more minutely examining these effects, I was led to refer them, and also the differences between wires and plates (714), to the solubility of the gases evolved, especially at the positive electrode

717 When the positive and negative electrodes *are equal in surface, the bubbles* which rise from them in dilute sulphuric acid are always different in character. Those from the positive plate are exceedingly small, and separate instantly from every part of the surface of the metal, in consequence of its perfect cleanliness (633) whilst in the liquid they give it a hazy appearance, from their number and minuteness, are easily carried down by currents and therefore not only present far greater surface of contact with the liquid than larger bubbles would do, but are retained a much longer time in mixture with it But the bubbles at the negative surface, though they constitute twice *the volume of the gas at the positive electrode*, are nevertheless very inferior in number They *do not rise so universally from every part of* the surface, but seem to be evolved at different points, and though so much larger, they appear to cling to the metal, separating with difficulty from it, and when separated, instantly rising to the top of the liquid If, therefore, oxygen and hydrogen had equal solubility in, or powers of combining with, water under similar circumstances, still under the present conditions the oxygen would be *far the most liable to solution*, but when to these is added its well *known power of forming a compound* with water, it is no longer surprising that such a compound should be produced in small quantities at the positive electrode and indeed the bleaching power which some philosophers have observed in a solution at this electrode, when chlorine and similar bodies have been carefully excluded, is probably due to the *formation* there, in this manner, of oxy-water.

718 That more gas was collect ... wires th ... circumst ... evolved ... having b ... to any pa ... larger, ha ... fluid by a ... shorter tim ... solution an

719 The ... *especially* b ... *was both a* ... and a proof of the solution of part of the gas evolved there The collected gas, when examined, was *found to* contain small portions of nitrogen This I attribute to the presence of air *dissolved in the* acid used for decomposition It is a well known *fact, that when bubbles of a gas but slightly* soluble in water or solutions pass through them, the portion of this gas which is dissolved displaces a portion of that previously in union with the liquid and so, in the decompositions under consideration, as the oxygen *dissolves*, it displaces a part of the air, or at least of the nitrogen, previously united *to the acid*, and

this effect takes place *most extensively* with large plates, because the gas evolved at them is in the most favourable condition for solution

720 With the intention of avoiding this solubility of the gases as much as possible, I arranged the decomposing plates in a vertical position (707, 708), that the bubbles might quickly escape upwards, and that the downward currents in the fluid should not meet ascending currents of gas This precaution I found to assist greatly in producing constant results, and especially in experiments to be hereafter referred to, in which other liquids than dilute sulphuric acid, as for instance solution of potash, were used

721 The irregularities in the indications of the measurer proposed, arising from the solubility just referred to, are but small, and may be very nearly corrected by comparing the results of two or three experiments They may also be almost entirely avoided by selecting that solution which is found to favour them in the least degree (728), and still further by collecting the hydrogen only, and using that as the indicating gas, for being much less soluble than oxygen, being evolved with twice the rapidity and in larger bubbles (717), it can be collected more perfectly and in greater purity

722. From the foregoing and many other experiments, it results that *variation in the size of the electrodes causes no variation in the chemical action of a given quantity of electricity upon water*

723 The next point in regard to which the principle of constant electro-chemical action was tested, was *variation of intensity* In the first place, the preceding experiments were repeated, using batteries of an *equal* number of plates, *strongly* and *weakly* charged but the results were alike They were then repeated, using batteries sometimes containing forty, and at other times only five pairs of plates, but the results were still the same *Variations therefore in the intensity*, caused by difference in the strength of charge, or in the number of alternations used, *produced no difference as to the equal action of large and small electrodes.*

724 Still these results did not prove that variation in the intensity of the current was not accompanied by a corresponding variation in the electro-chemical effects, since the actions at *all* the surfaces might have increased or diminished together The deficiency in the evidence is, however, completely supplied by the former experiments on different sized electrodes, for with variation in the size of these, a variation in the intensity must have occurred The intensity of an electric current traversing conductors alike in their nature, quality, and length, is probably as the quantity of electricity passing through a given sectional area perpendicular to the current, divided by the time (360, *note*) and therefore when large plates were contrasted with wires separated by an equal length of the same decomposing conductor (714), whilst one current of electricity passed through both arrangements, that electricity must have been in a very different state, as to *tension*, between the plates and between the wires yet the chemical results were the same

725 The difference in intensity, under the circumstances described, may be easily shown practically, by arranging two decomposing apparatus as in Pl VI, *Fig 12* where the same fluid is subjected to the decomposing power of the same current of electricity, passing in the vessel A between large platina plates, and in the vessel B between small wires If a third decomposing apparatus, such as that delineated Pl VI, *Fig 11* (711), be connected with the wires at *a b*, Pl VI, *Fig 12*, it will serve sufficiently well, by the degree of decomposition occurring in it, to indicate the relative state of the two plates as to intensity and if it then be applied in the same way, as a test of the state of the wires at *a' b'*, it will, by the increase of decomposition within show how much greater the intensity is there than at the former points The connexions of P and N with the voltaic battery are of course to be continued during the whole time

726 A third form of experiment in which difference of intensity was obtained, for the purpose of testing the principle of equal chemical action, was to arrange three volta-electrometers, so that after the electric current had passed through one, it should divide into two parts each of which should traverse one of the remaining instruments, and should then reunite The sum of the decomposition in the two latter vessels was always equal to the decomposition in the former vessel But the *intensity* of the divided current could not be the same as that it had in its original state and therefore *variation of intensity has no influence on the results if the quantity of electricity remain the same* The experiment, in fact, resolves itself simply into an increase in the size of the electrodes (725)

727 The *third point*, in respect to which the principle of equal electro-chemical action on

stances which would require to be practically guarded against

714 The first point investigated was the influence or indifference of extensive variations in the size of the electrodes, for which purpose instruments like those last described (709, 710, 711) were used One of these had plates 0 7 of an inch wide, and nearly four inches long, another had plates only 0 5 of an inch wide and 0 8 of an inch long a third had wires 0 02 of an inch in diameter, and three inches long, and a fourth similar wires only half an inch in length Yet when these were filled with dilute sulphuric acid, and, being placed in succession, had one common current of electricity passed through them, very nearly the same quantity of gas was evolved in all The difference was sometimes in favour of one and sometimes on the side of another, but the general result was that the largest quantity of gases was evolved at the smallest electrodes, namely, those consisting merely of platina wires

715 Experiments of a similar kind were made with the single-plate straight tubes (707), and also with the curved tubes (708), with similar consequences, and when these, with the former tubes, were arranged together in various ways the result as to the equality of action of large and small metallic surfaces when delivering and receiving the same current of electricity, was constantly the same As an illustration the following numbers are given An instrument with two wires evolved 74 3 volumes of mixed gases another with plates 73 25 volumes whilst the sum of the oxygen and hydrogen in two separate tubes amounted to 73 65 volumes In another experiment the volumes were 55.3, 55 3, and 54.4

716 But it was observed in these experiments, that in single-plate tubes (707) more hydrogen was evolved at the negative electrode than was proportionate to the oxygen at the positive electrode, and generally, also, more than was proportionate to the oxygen and hydrogen in a double-plate tube Upon more minutely examining these effects, I was led to refer them, and also the differences between wires and plates (714), to the solubility of the gases evolved, especially at the positive electrode

717 When the positive and negative electrodes are equal in surface, the bubbles which rise from them in dilute sulphuric acid are always different in character Those from the positive plate are exceedingly small and separate instantly from every part of the surface of the metal, in consequence of its perfect cleanliness (633) whilst in the liquid they give it a hazy appearance, from their number and minuteness, are easily carried down by currents and therefore not only present far greater surface of contact with the liquid than larger bubbles would do, but are retained a much longer time in mixture with it But the bubbles at the negative surface, though they constitute twice the volume of the gas at the positive electrode, are nevertheless very inferior in number They do not rise so universally from every part of the surface, but seem to be evolved at different points and though so much larger, they appear to cling to the metal, separating with difficulty from it, and when separated, instantly rising to the top of the liquid If, therefore oxygen and hydrogen had equal solubility in or powers of combining with, water under similar circumstances, still under the present conditions the oxygen would be far the most liable to solution but when to these is added its well-known power of forming a compound with water, it is no longer surprising that such a compound should be produced in small quantities at the positive electrode and indeed the bleaching power which some philosophers have observed in a solution at this electrode, when chlorine and similar bodies have been carefully excluded, is probably due to the formation there, in this manner, of oxy water

718 That more gas was collected from the wires than from the plates, I attribute to the circumstance, that as equal quantities were evolved in equal times, the bubbles at the wires having been more rapidly produced, in relation to any part of the surface, must have been much larger have been therefore in contact with the fluid by a much smaller surface and for a much shorter time than those at the plates, hence less solution and a greater amount collected.

719 There was also another effect produced especially by the use of large electrodes which was both a consequence and a proof of the solution of part of the gas evolved there The collected gas, when examined, was found to contain small portions of nitrogen. This I attribute to the presence of air dissolved in the acid used for decomposition It is a well known fact that when bubbles of a gas but slightly soluble in water or solutions pass through them the portion of this gas which is dissolved displaces a portion of that previously in union with the liquid and so in the decompositions under consideration as the oxygen dissolves, it displaces a part of the air, or at least of the nitrogen, previously united to the acid, and

measurer, it may be desirable to collect the hydrogen only, as being less liable to absorption or disappearance in other ways than the oxygen whilst at the same time its volume is so large, as to render it a good and sensible indicator In such cases the first and second form of apparatus have been used, Pl VI, *Figs 7, 8* (707, 708) The indications obtained were very constant, the variations being much smaller than in those forms of apparatus collecting both gases and they can also be procured when solutions are used in comparative experiments, which, yielding no oxygen or only secondary results of its action can give no indications if the educts at both electrodes be collected Such is the case when solutions of ammonia, muriatic acid chlorides, iodides, acetates or other vegetable salts, &c , are employed

735 In a few cases, as where solutions of metallic salts liable to reduction at the negative electrode are acted upon, the oxygen may be advantageously used as the measuring substance This is the case, for instance, with sulphate of copper

736 There are therefore two general forms of the instrument which I submit as a measur

observation, but when used as an *absolute measurer*, it will be needful that the barometric pressure and the temperature be taken into ac-

GREE of electricity

737 It can scarcely be needful to point out further than has been done how this instru-

volume of gas for changes in temperature and pressure and especially for moisture [1] For the latter object the volta-electrometer (Pl VI, *Fig 11*) is most accurate as its gas can be measured over water, whilst the others retain it over acid or saline solutions

738 I have not hesitated to apply the term *degree* (736), in analogy with the use made of it with respect to another most important imponderable agent, namely, heat, and as the definite expansion of air, water, mercury, &c , is there made use of to measure heat, so the equally definite evolution of gases is here turned to

by variations in time or intensity, or altera

fore named it a VOLTA ELECTROMETER

¶ vi *On the Primary or Secondary Character of the Bodies Evolved at the Electrodes*

742 Before the *volta-electrometer* could be employed in determining, as a *general law* the constancy of electro-decomposition, it became necessary to examine a distinction, already recognised among scientific men relative to the

[1] For a simple table of correction for moisture I ... of referring to my *Chemical*

water was tested, was *variation of the strength of the solution used* In order to render the water a conductor, sulphuric acid had been added to it (707), and it did not seem unlikely that this substance, with many others, might render the water more subject to decomposition, the electricity remaining the same in quantity But such did not prove to be the case Diluted sulphuric acid, of different strengths, was introduced into different decomposing apparatus, and submitted simultaneously to the action of the same electric current (714) Slight differences occurred as before, sometimes in one direction, sometimes in another, but the final result was, that *exactly the same quantity of water was decomposed in all the solutions by the same quantity of electricity*, though the sulphuric acid in some was seventy fold what it was in others The strengths used were of specific gravity 1 495, and downwards

728 When an acid having a specific gravity of about 1 336 was employed, the results were most *uniform*, and the *oxygen* and *hydrogen* (716) most constantly in the right proportion to each other Such an acid gave more gas than one much weaker acted upon by the same current, apparently because it had less solvent power If the acid were very strong, then a remarkable disappearance of oxygen took place, thus, one made by mixing two measures of strong oil of vitriol with one of water gave forty-two volumes of hydrogen, but only twelve of oxygen. The hydrogen was very nearly the *same with that evolved from acid of the specific gravity* 1 232 I have not yet had time to examine minutely the circumstances attending the disappearance of the oxygen in this case, but imagine it is due to the formation of oxywater, which Thénard has shown is favoured by the presence of acid

729 Although not necessary for the practical use of the instrument I am describing, yet as connected with the important point of *constant electro-chemical action upon water*, I now investigated the effects produced by an electric current passing through aqueous solutions of acids, salts, and compounds, exceedingly different from each other in their nature, and found them to yield astonishingly uniform results But many of them which are connected *with a secondary action* will be more usefully described hereafter (778)

730 When solutions of caustic potassa or soda, or sulphate of magnesia, or *sulphate of soda*, were acted upon by the electric current, just as much oxygen and hydrogen was evolved from them as from the diluted sulphuric acid, with which they were compared When a *solution of ammonia, rendered a better conductor* by sulphate of ammonia (554) or a solution of subcarbonate of potassa was experimented with, the *hydrogen* evolved was in the *same quantity as that set free from the diluted sulphuric acid with which they were compared* Hence *changes in the nature of the solution do not alter the constancy of electrolytic action upon water*

731 I have already said, respecting large and small electrodes, that change of order caused no change in the general effect (715) The same was the case with different solutions, or with different intensities, and however the circumstances of an experiment might be varied, *the results came forth exceedingly* consistent, and proved that the electro-chemical action was still the same

732 *I consider the foregoing* investigation as sufficient to prove the very extraordinary and important principle with respect to WATER, *that when subjected to the influence of the electric current, a quantity of it is decomposed exactly proportionate to the quantity of electricity which has passed*, notwithstanding the thousand variations in the conditions and circumstances under which it may at the time be placed and further, that when the interference of certain secondary effects (*742, &c*), together with the *solution or recombination of* the gas and the evolution of air, are guarded against, *the products of the decomposition may be collected with such accuracy, as to afford a very excellent and valuable measurer of the electricity concerned in their evolution*

733 The forms of instrument which I have given, *Pl VI, Figs 9, 10, 11* (709, 710 711), are probably those which will be found most useful, as they indicate the quantity of electricity by the largest volume of gases and cause the least obstruction to the passage of the current The fluid which my present experience leads me to prefer is a solution of *sulphuric acid of specific gravity about* 1.336, or from that to 1 25, but it is very essential that there should be no organic substance, nor any vegetable acid, nor other body, which, *by being* liable to the action of the oxygen or hydrogen evolved at the electrodes (773, &c), shall diminish their quantity, or add other gases to them.

734 In many cases when the instrument is used as a *comparative standard*, or even as a

555) A n re st on n 1 . . .

ing, but being as 1 to about 3 or 4 This result would seem at first to imply that the electric current had decomposed ammonia, and that the nitrogen had been determined towards the positive electrode But when the electricity used was measured out by the volta-electrom eter (707, 736) . . .

ter, whilst the nitrogen had no certain or constant relation whatever When upon multiplying experiments, it was found that, by using a stronger or weaker solution, or a more or less powerful battery, the gas evolved at the *anode* was a mixture of oxygen and nitrogen, varying both in proportion and absolute quantity, whilst the hydrogen at the *cathode* re-

of the nascent oxygen, determined to that surface by the electric current, upon the ammonia in solution It was the water, *therefore*, which was electrolyzed, not the ammonia Further, the experiment gives no real indication of the tendency of the element nitrogen to either one electrode or the other, nor do I know of any experiment with nitric acid, or other compounds of nitrogen, which shows the tendency of this element under the . . .

tassa may be quoted When a very strong solution was used, more gas was evolved at the *anode* than at the *cathode*, in the propor tion of 4 to 3 nearly that from the *anode* was a mixture of carbonic oxide and carbonic acid that from the *cathode* pure hydrogen. When a much weaker solution was used, less gas was evolved at the *anode* than at the *cathode*, and it now contained carburetted hydrogen as well as carbonic oxide and carbonic acid. This result of carburetted hydrogen at the positive electrode has a very anomalous appearance, if considered as an immediate consequence of the decomposing power of the current It how ever, as well as the carbonic oxide and acid, is only a *secondary result*, for it is the water alone which suffers electro-decomposition, and it is the oxygen eliminated at the *anode* which, reacting on the acetic acid, in the *midst of* . . .

(707) for then the hydrogen evolved from the acetate at the *cathode* is always found to be definite, being exactly proportionate to the electricity which has passed through the solution, and, *in quantity, the same as the hydrogen evolved in the volta-electrometer itself* The appearance of the carbon in combination with the hydrogen at the positive electrode, and its non appearance at the negative electrode, are in curious contrast with the results which might have been expected from the law usually accepted respecting the final places of the elements

750 If the salt in solution be an acetate of lead, then the results at both electrodes are secondary and cannot be used to estimate or express the amount of electro-chemical action, except by a circuitous process (843) In place . . .

taining for instance peroxides, as that of copper, combined with this or any other decomposable acid, still more complicated results will be obtained which viewed as direct *results of* the electro-chemical action, will, in their proportions, present nothing but confusion, but will appear perfectly harmonious and simple if they be considered as secondary results, and will accord in their proportions with the oxygen and hydrogen evolved from water by the action of a definite quantity of electricity

751 I have experimented upon many bodies, with a view to determine whether the results were primary or secondary *I have been surprised to find how many of them in ordinary cases are of the latter class, and how frequently water is the only body electrolyzed in instances where other substances have been sup-*

products of that action, namely, their primary or secondary character, and, if possible, by some general rule or principle, to decide when they were of the one or the other kind It will

of results together

743 When a substance under decomposition yields at the electrodes those bodies uncombined and unaltered which the electric current has separated then they may be considered as primary results, even though themselves compounds Thus the oxygen and hydrogen from water are primary results, and so also are the acid and alkali (themselves compound bodies) evolved from sulphate of soda But when the substances separated by the current are changed

744 These secondary results occur in two ways, being sometimes due to the mutual action of the evolved substance and the matter of the electrode, and sometimes to its action upon the substances contained in the body itself under decomposition Thus, when carbon is made the positive electrode in dilute sulphuric acid, carbonic oxide and carbonic acid occasionally appear there instead of oxygen, for the latter, acting upon the matter of the electrode produces these secondary results Or if the positive electrode, in a solution of nitrate or acetate of lead be platina then peroxide of lead appears there, equally a secondary result with the former, but now depending upon an action of the oxygen on a substance in the solution Again, when ammonia is decomposed by platina electrodes nitrogen appears at the *anode*,[1] but though an *elementary* body, it is a *secondary* result in this case, being derived

evolved at the *cathode*, though elements are *always* secondary results, and not immediate consequences of the decomposing power of

tained by feeble electric currents ... ture, but they are essentially chemical, and must, in the theory of electrolytic action be carefully distinguished from those which are directly due to the action of the electric current

746 The nature of the substances evolved will often lead to a correct judgement of their primary or secondary character, but is not suf

occasions evidently viewed as a primary result [2] but I think I shall show, that when it

be a primary result These, however I expect to prove, are all secondary results the mere consequence of chemical action, and no proofs either of the attraction or of the law announced respecting their places [4]

747 But when we take to our assistance the

nature of the substances set free a generally accurate judgement of the primary or secondary character of the results may be formed

are not affected), and what are the results be expected may be established with such degree of certainty as to remove innumerable ambiguities and doubtful considerations from this branch of the science

[1] *Annales de Chimie* 1804 Vol LI p 167

[2] *Annales de Chimie* 1804 Vol LI p 172 ... 144 161

becoming a bad conductor of electricity, sulphuric acid was added to it this caused more ready decomposition, but did not sensibly alter the proportion of chlorine and oxygen

761 The muriatic acid was now diluted with 100 times its volume of dilute sulphuric acid It still gave a large proportion of chlorine at the *anode*, mingled with oxygen, and the result was the same, whether a voltaic battery of 40

therefore the chlorine would have been 30 volumes had it not been dissolved by the fluid

762 Next with respect to the quantity of elements evolved On using the volta-electrometer, it was found that, whether the strongest

same quantity of electricity could evolve from water

763 This constancy does not decide whether the muriatic acid is electrolyzed or not, although it proves that, if so, it must be in definite proportions to the quantity of electricity used

equivocal depending on the simultaneous presence of it and oxygen is involved the chlorine

with these considerations I conclude that muriatic acid is decomposed by the direct influence of the electric current, and that the quantities evolved are, and therefore the chemical action is *definite for a definite quantity of electricity* For though I have not collected and measured the chlorine, in its separate state, at the *anode* there can exist no doubt as to its being proportional to the hydrogen at the *cathode*, and the results are therefore sufficient to establish the

composed, giving origin to the oxygen, which

ing unaffected

766 *Chlorides* On using solutions of chlorides in water—for instance, the chlorides of sodium or calcium—there was evolution of chlorine only at the positive electrode, and of hydrogen, with the oxide of the base as soda or lime at the negative electrode The process of decomposition may be viewed as proceeding in two or three ways all terminating in the same results Perhaps the simplest is to consider the chloride as the substance *electrolyzed* its chlorine being *determined to* and *evolved at* the *anode* and its metal passing to the *cathode*, where,

ration of nitric oxide Upon diluting the acid with its bulk or more of water, gas appeared at the negative electrode Its quantity could be varied by variations, either in the strength of the acid or of the voltaic current for that acid from which no gas separated at the *cathode*, with a weak voltaic battery, did evolve gas there with a stronger, and that battery which evolved no gas there with a strong acid, did cause *its evolution* with an acid more dilute The gas at the *anode* was always oxygen, that at the *cathode* hydrogen When the quantity of products was examined by the volta electrometer (707), the oxygen, whether from strong or weak acid, proved to be in the same proportion as from water When the acid was diluted to specific gravity 1 24, or less, the hydrogen also proved to be the same in quantity as from water. Hence I conclude that the nitric acid does not undergo electrolyzation, but the water only, that the oxygen at the *anode* is always a primary result, but that the products at the *cathode* are often secondary, and due to the reaction of the hydrogen upon the nitric acid

753 *Nitre* A solution of this salt yields very variable results, according as one or other form of tube is used, or as the electrodes are large or small Sometimes the whole of the hydrogen of the water decomposed may be obtained at the negative electrode, at other times, only a part of it, because of the ready formation of secondary results The solution is a very excellent conductor of electricity

754 *Nitrate of ammonia*, in aqueous solution, gives rise to secondary results very varied and uncertain in their proportions

755 *Sulphurous acid* Pure liquid sulphurous acid does not conduct nor suffer decomposition by the voltaic current,[1] but, when dissolved in water, the solution acquires conducting power, and is decomposed, yielding oxygen at the *anode*, and hydrogen and sulphur at the *cathode*

756 A solution containing sulphuric acid in addition to the sulphurous acid, was a better conductor It gave very little gas at either electrode that at the *anode* was oxygen, that at the *cathode* pure hydrogen From the *cathode* also rose a white turbid stream, consisting of diffused sulphur, which soon rendered the whole solution milky The volumes of gases were in no regular proportion to the quantities evolved from water in the voltameter I conclude that the sulphurous acid was not at all affected by the electric current in any of these cases, and that the water present was the only body electro-chemically decomposed, that, at the *anode* the oxygen from the water converted the sulphurous acid into sulphuric acid, and, at the *cathode*, the hydrogen electrically evolved decomposed the sulphurous acid, combining with its oxygen, and setting its sulphur free I conclude that the sulphur at the negative electrode was only a secondary result and in fact no part of it was found combined with the small portion of hydrogen which escaped when weak solutions of sulphurous acid were used

757 *Sulphuric acid* I have already given my reasons for concluding that sulphuric acid is not electrolyzable, i e, not decomposable directly by the electric current, but occasionally suffering by a secondary action at the *cathode* from the hydrogen evolved there (681) In the year 1800, Davy considered the sulphur from sulphuric acid as the result of the action of the nascent hydrogen[2] In 1804, Hisinger and Berzelius stated that it was the direct result of the action of the voltaic pile,[3] an opinion which from that time Davy seems to have adopted and which has since been commonly received by all The change of my own opinion requires that I should correct what I have already said of the decomposition of sulphuric acid in a former series of these *Researches* (552) I do not now think that the appearance of the sulphur at the negative electrode is an immediate consequence of electrolytic action.

758 *Muriatic acid* A strong solution gave hydrogen at the negative electrode, and chlorine only at the positive electrode of the latter, a part acted on the platina and a part was dissolved A minute bubble of gas remained it was not oxygen, but probably air previously held in solution

759 It was an important matter to determine whether the chlorine was a primary result, or only a secondary product, due to the action of the oxygen evolved from water at the *anode* upon the muriatic acid, i e, whether the muriatic acid was electrolyzable, and if so, whether the decomposition was *definite*

760 The muriatic acid was gradually diluted One part with six of water gave only chlorine at the *anode* One part with eight of water gave only chlorine, with nine of water, a little oxygen appeared with the chlorine but the occurrence or non-occurrence of oxygen at these

[1] See also De la Rive *Bibliothèque Universelle*, Vol XL, p 205 or *Quarterly Journal of Science* Vol XXVII p 407

[2] *Nicholson's Quarterly Journal*, Vol IV, pp. 280, 281

[3] *Annales de Chimie*, 1804, Vol LI p. 173.

[illegible]

It still gave a large proportion of chlorine at the *anode*, mingled with oxygen, *and the result* was the same, whether a voltaic battery of 40 [illegible]

[illegible] umes, had it not been dissolved by the fluid

762 Next with respect to the quantity of el- [illegible]

[illegible] er chlorine alone or chlorine mingled with oxygen appeared at the *anode*, still the hydrogen evolved at the *cathode* was a constant quantity, i e, exactly the same as the hydrogen which the *same quantity of electricity* could evolve from water.

763 This constancy does not decide whether the muriatic acid is electrolyzed or not, although it proves that, if so, it must be in defi- [illegible]

[illegible] process of electro-decomposition They both unite with it in single proportional or equivalent quantities; and the number of proportionals [illegible]

[illegible] even [illegible]

[illegible] evolved are, and therefore the chemical action is, *definite for a definite quantity of electricity* For though I have not collected and measured the chlorine, in its separate state, at the *anode there can exist no doubt as to its being proportional* to the hydrogen at the *cathode*, and the results are therefore sufficient to establish the general law of *constant electro-chemical action* in the case of muriatic acid

765 In the dilute acid (761), I conclude that a part of the water is electro-chemically decomposed, giving origin to the oxygen, which appears mingled with the chlorine at the *anode* The oxygen *may* be viewed as a secondary result, but I incline to believe that it is not so, for, if it were, it might be expected in largest proportion from the stronger acid, whereas the reverse is the fact This consideration, with others, also leads me to conclude that muriatic acid is more easily decomposed by the electric current than water, since, even when diluted with eight or nine times its quantity of the latter fluid, it alone gives way, the water remaining unaffected

766 *Chlorides* On using solutions of chlorides in water—for instance, the chlorides of sodium or calcium—there was evolution of chlorine only at the positive electrode, and of hydrogen, with the oxide of the base, as soda or lime, at the negative electrode The process of decomposition may be viewed as proceeding in two or three ways, all terminating in the same results Perhaps the simplest is to consider the [illegible]

[illegible] present. It is, however, of *great consequence* to state, that, on using the volta-electrometer, the hydrogen in both cases was definite, and if [illegible]

[illegible] do support the *general law*.

proportion to the quantity of electricity which had passed i e , in the same proportion as was evolved by the same current from water, and iodine without any oxygen was evolved at the positive electrode But when diluted, small

driodic acid in this case to be direct, for the reasons already given respecting muriatic acid (763, 764)

769 *Iodides* A solution of iodide of potassium being subjected to the voltaic current, iodine appeared at the positive electrode (without any oxygen) and hydrogen with free alkali

770 *Hydro-fluoric acid and fluorides* Solution of hydrofluoric acid did not appear to be decomposed under the influence of the electric

tained *fluorine* in the separate state I think it better to refer to a future series of these *Researches*, in which I purpose giving a fuller account of the results than would be consistent with propriety here[1]

771 *Hydro-cyanic acid* in solution conducts very badly The definite proportion of hydrogen (equal to that from water) was set free at the *cathode*, whilst at the *anode* a small quan-

ic acid was made a better conductor by sulphuric acid, the same results occurred

Cyanides With a solution of the cyanide of

positive electrode,[2] I incline to believe that the cyanide in solution is *directly* decomposed

772 *Ferro-cyanic acid* and the *ferro-cyanides* as also *sulpho-cyanic acid* and the *sulpho-cyanides* presented results corresponding with those just described (771)

773 *Acetic acid* Glacial acetic acid, when

more water, it acted slowly and about as pure water would do Dilute sulphuric acid was added to it in order to make it a better conductor then the definite proportion of hydrogen

rent and other circumstances

774 *Acetates* One of these has been referred to already, as affording only secondary results relative to the acetic acid (749) With many of the metallic acetates the results at both electrodes are secondary (746 750)

Acetate of soda fused and anhydrous is directly decomposed being as I believe a true electrolyte, and evolving soda and acetic acid at the *cathode* and *anode* These however have no sensible duration but are immediately resolved into other substances charcoal sodi

hydrogen at the negative electrode remained constant unless certain triple metallic salts were used

776 Solutions, of salts containing other vegetable acids as the benzoates of sugar, gum,

[1] I have not obtained fluorine my expectat ons

[2] It is a very remarkable thing to see carbon and nitrogen in this case determined powerfully towards the positive surface of the voltaic battery but it is perfectly in harmony with the theory of electro-chemical decomposition which I have advanced.

&c., dissolved in dilute sulphuric acid; of resin, albumen, &c., dissolved in alkalies, were in turn submitted to the electrolytic power of the voltaic current. In all these cases, secondary results to a greater or smaller extent were produced at the positive electrode.

777. In concluding this division of these *Researches*, it cannot but occur to the mind that the final result of the action of the electric current upon substances, placed between the electrodes, instead of being simple may be very complicated. There are two modes by which these substances may be decomposed, either by the direct force of the electric current, or by the action of bodies which that current may evolve. There are also two modes by which [illegible]

with those bodies, which being contained in, or associated with, the body suffering decomposition, are necessarily present at the *anode* and *cathode*. The complexity is rendered still greater by the circumstance that two or more of these actions may occur simultaneously, and also in variable proportions to each other. But it may in a great measure be resolved by attention to the principles already laid down (747).

778 When *aqueous* solutions of bodies are used, secondary results are exceedingly frequent. [illegible] present in [illegible]

Davy's decomposition of the hydrates of potassa and soda, a part of the potassium produced was the result of a secondary action. Hence also a fre[illegible] cause for the d[illegible]appear-

[illegible] that a secondary [illegible]

[illegible] water is pres-

[illegible]

acts on the platina and forms a compound with it, which dissolves; but when protochloride of tin is used, the chlorine at the *anode* does not act upon the platina, but upon the chloride already there, forming a perchloride which rises in vapour (790, 804). These are, therefore, instances of secondary actions of both kinds, produced in bodies containing no water.

780. The production of boron from fused borax (402, 417) is also a case of secondary action; for boracic acid is not decomposable by electricity (408), and it was the sodium evolved at the *cathode* which, reacting on the boracic acid around it, took oxygen from it and set boron free in the experiments formerly described.

781. Secondary actions have already, in the [illegible] It is probable that [illegible]

position, and perhaps even the arrangement, of the particles of such bodies as the vegetable [illegible]

the action seems the more promising, because of the thorough command which we possess over attendant circumstances, such as the strength of the current, the size of the electrodes, the nature of the decomposing conductor, its strength, &c., all of which may be expected to have their corresponding influence upon the final result.

782. It is to me a great satisfaction that the extreme variety of secondary results has presented nothing opposed to the doctrine of a constant and definite electro-chemical action, to the particular consideration of which I shall now proceed.

[illegible] Definite Nature and Extent of [illegible]

[illegible]

law, derived from experiment, which seemed [illegible] to the science [illegible]

784 In the further progress of the successive investigations, I have had frequent occasion to refer to the same law, sometimes in circumstances offering powerful corroboration of its truth (456, 504, 505), and the present series already supplies numerous new cases in which it holds good (704, 722, 726, 732) It is now my object to consider this great principle more closely, and to develop some of the consequences to which it leads That the evidence for it may be the more distinct and applicable, I shall quote cases of decomposition subject to as few interferences from secondary results as possible, effected upon bodies very simple, yet very definite in their nature

785 In the first place, I consider the law as so fully established with respect to the decomposition of *water*, and under so many circumstances which might be supposed, if anything could, to exert an influence over it, that I may be excused entering into further detail respecting that substance, or even summing up the results here (732) I refer, therefore, to the whole of the subdivision of this series of *Researches* which contains the account of the *volta-electrometer* (704, &c)

786 In the next place, I also consider the law as established with respect to *muriatic acid* by the experiments and reasoning already advanced, when speaking of that substance, in the subdivision respecting primary and secondary results (758, &c)

787 I consider the law as established also with regard to *hydriodic acid* by the experiments and considerations already advanced in the preceding division of this series of *Researches* (767, 768)

788 *Without speaking with the same confidence*, yet from the experiments described, and many others not described, relating to hydrofluoric, hydro-cyanic, ferro-cyanic, and sulphocyanic acids (770, 771, 772), and from the close analogy which holds between these bodies and the hydracids of chlorine, iodine, bromine, &c , I consider these also as coming under subjection to the law, and assisting to prove its truth

789 In the preceding cases, except the first, the water is believed to be inactive, but to avoid any ambiguity arising from its presence, I sought for substances from which it should be absent altogether, and, taking advantage of the law of conduction already developed (380, &c), I soon found abundance, amongst which *protochloride of tin* was first subjected to decomposition in the following manner A piece of platina wire had one extremity coiled up into a small knob, and, having been carefully weighed, was sealed hermetically into a piece of bottle-glass tube, so that the knob should be at the bottom of the tube within (Pl VI, *Fig 13*) The tube was suspended by a piece of platina wire, so that the heat of a spirit-lamp could be applied to it Recently fused protochloride of tin was introduced in sufficient quantity to occupy, when melted, about one-half of the tube, the wire of the tube was connected with a volta-electrometer (711), which was itself connected with the negative end of a voltaic battery, and a platina wire connected with the positive end of the same battery was dipped into the fused chloride in the tube, being however so bent, that it could not by any shake of the hand or apparatus touch the negative electrode at the bottom of the vessel The whole arrangement is delineated in Pl. VI, *Fig 14*

790 Under these circumstances the chloride of tin was decomposed the chlorine evolved at the positive electrode formed bichloride of tin (779), which passed away in fumes, and the tin evolved at the negative electrode combined with the platina, forming an alloy, fusible at the temperature to which the tube was subjected, and therefore never occasioning metallic communication through the decomposing chloride When the experiment had been continued so long as to yield a reasonable quantity of gas in the volta-electrometer, the battery connexion was broken, the positive electrode removed, and the tube and remaining chloride allowed to cool When cold, the tube was broken open, the rest of the chloride and the glass being easily separable from the platina wire and its button of alloy The latter when washed *was then reweighed, and the increase* gave the weight of the tin reduced

791 I will give the particular results of one experiment, in illustration of the mode adopted in this and others, the results of which I shall have occasion to quote The negative electrode weighed at first 20 grains after the experiment, it, with its button of alloy, weighed 23 2 grains The tin evolved by the electric current at the *cathode* weighed therefore 3.2 grains The quantity of oxygen and hydrogen collected in the volta-electrometer = 3.85 cubic inches As 100 cubic inches of oxygen and hydrogen, in the proportions to form water, may be considered as weighing 12 92 grains, the 3 85 cubic inches would weigh 0 49742 of a grain that being, therefore, the weight of water decomposed by the same electric current as was able to decompose such weight of protochloride of

tin as could yield 3 2 grains of metal Now 0 49742 3 2 9, the equivalent of water is to 57 9, which should therefore be the equivalent of tin, if the experiment had been made without error, and if the electro chemical decomposition *is in this case also definite* In some chemical works 58 is given as the chemical equivalent of tin, in others 57 9 Both are so near to the result of the experiment, and the experiment itself is so subject to slight causes of variation (as from the absorption of gas in the volta-electrometer [716], &c), that the numbers leave little doubt of the applicability of the *law of definite action* in this and all similar cases of electro-decomposition

792 It is not often I have obtained an accordance in numbers so near as that I have just quoted Four experiments were made on the

periments gave 58 53 as the electro-chemical equivalent for tin

793 The chloride remaining after the experiment was pure protochloride of tin and no one can doubt for a moment that the equivalent of chlorine had been evolved at the *anode*, and, having formed bichloride of tin as a secondary result, had passed away

794 *Chloride of lead* was experimented upon in a manner exactly similar, except that a change was made in the nature of the positive elec-

portion of platina can pass to the *cathode*, and would then produce a vitiated result I there-

not act upon it, but is evolved in *the free state*, and the pl ... under the

they can do no harm in the chloride

795 The mean of three experiments gave the number of 100 85 as the equivalent for lead The chemical equivalent is 103 5 The deficiency in my experiments I attribute to the solution of part of the gas (716) in the volta-electrometer, but the results leave no doubt on my mind that both the lead and the chlorine are, in this case, evolved in *definite quantities* by the action of a given quantity of electricity (814, &c)

796 *Chloride of antimony* It was in endeavouring to obtain the electro-chemical equivalent of antimony from the chloride, that I found reasons for the statement I have made respecting the presence of water in it in an earlier part of these *Researches* (690, 693, &c)

797 I endeavoured to experiment upon the *oxide of lead* obtained by fusion and ignition of the nitrate in a platina crucible, but found great difficulty, from the high temperature required for perfect fusion, and the powerful

platina wire was employed for the positive electrode, that metal not being subject to any action from the oxygen evolved against it The arrangement is given in Pl VI, *Fig 16*

798 In an experiment of this kind the equiv-

duced at the *cathode*, and re-oxidize it When I endeavoured to correct this by having more litharge, the greater heat required to keep it all fluid caused a quicker action on the crucible, which was soon eaten through, and the experiment stopped

799 In one experiment of this kind I used

trode, and retard the transfer of electricity. The number for lead came out 101 29, which is *so near to 103 5 as to show that the action of* the current had been definite

800 *Oxide of bismuth* I found this substance required too high a temperature, and acted too *powerfully as a flux, to allow of any experiment*

which consists of one proportional of metal and one and a half of oxygen, was subjected to the action of the electric current in a green-glass tube (789), surrounded by a jacket of platina foil, and heated in a charcoal fire The decom-

tions as made it amenable to the power of the electric current This effect I have already given reasons for supposing may be due to the presence of a true protoxide, consisting of sin-

soluble in the protoxide, formed a crystalline crust around the positive electrode, and thus insulating it, prevented the transmission of the electricity Whether if it had been fusible and still immiscible, it would have decomposed, is doubtful, because of its departure from the required composition (697) It was a very natural secondary product at the positive elec-

802 *Iodide of lead* This substance can be experimented with in *tubes heated by a spirit-lamp* (789), *but I obtained no good results* from it, whether I used positive electrodes of

of it, becoming itself again protiodide Such a periodide does exist, and it is very rarely that

the iodide of lead formed by precipitation, and well-washed, can be fused without evolving much iodine, from the presence of this per-compound, nor does crystallization from its hot aqueous solution free it from this substance Even when a little of the protiodide and iodine

in the liquid into contact with the cathode

803 This view of the result was strengthened by a third experiment, where the space between the electrodes was increased to one-third of an inch, *for now the interfering effects were*

sideration, but on the contrary may, from general considerations, be admitted as included in it

804 *Protiodide of tin* This substance, when fused (402), conducts and is decomposed by the electric current, tin is evolved at the *anode*, and periodide of tin as a secondary result

and other circumstances, prevented me from

mer cases

806 In some of these experiments several substances were placed in succession, and decomposed simultaneously by the *same electric*

[1] This paragraph is subject to the corrective note now appended to paragraph 696.—*Dec* 1838

parable, the tin, lead, chlorine, oxygen, and hydrogen evolved being *definite in quantity* and electro-chemical equivalents to each other

807 *Let us turn to another kind of proof of* the *definite chemical action of electricity* If any circumstances could be supposed to exert an *influence* over the quantity of the matters evolved during electrolytic action one would *expect them* to be persent when electrodes of *different substances*, and possessing very different chemical affinities for such matters, were *used* Platina has no power in dilute sulphuric acid of combining with the oxygen at the *anode*, though the latter be evolved in the nascent state against it Copper, on the other hand, immediately unites with the oxygen, as the electric current sets it free from the hydrogen, and zinc is not only able to combine with it, but can, without any help from the electricity, abstract it directly from the water, at the same time setting torrents of hydrogen *free* Yet in cases where these three substances were used as the positive electrodes in three

808 The experiment was made thus Portions of the dilute sulphuric acid were put into three basins Three volta electiometer tubes, of the form, Pl VI, *Figs 5, 7*, were filled with

nected with the negative electrode of the *first* basin and a platina plate, which dipped into

tery

gen was evolved at the positive copper elec-

trode in the second basin, but a sulphate of copper was formed there, whilst in the third basin the positive platina electrode evolved pure oxygen gas and was itself unaffected *But in all* the basins the hydrogen liberated at the *negative* platina electrodes was *the same in quantity*, and the same with the volume of hydrogen evolved in the volta-electrometer, showing that in all the vessels the current had decomposed an equal quantity of water In this trying case, therefore, the *chemical action of electricity* proved to be *perfectly definite*

810 A similar experiment was made with muriatic acid diluted with its bulk of water The three positive electrodes were zinc, silver,

The three negative electrodes were, as before, platina plates fixed within glass tubes In this

results prove that the quantities so decomposed

trode in both sulphuric and muriatic acids

ver wire being used as the electrodes, and a volta-electrometer included in the circuit Great care was taken to withdraw the negative electrodes so regularly and steadily that the crystals of reduced silver should not form a metallic communication beneath the surface of the fused chloride On concluding the experiment the positive electrode was re-weighed, and its loss ascertained The mixture of chloride of silver, and metal, withdrawn in successive portions at the negative electrode, was digested in solution of ammonia, to remove the chloride, and the metallic silver remaining also weighed it was the reduction at the *cathode*, and exactly equalled the solution at the *anode* and each portion was as nearly as possible the equivalent to the water decomposed in the volta-electrometer.

814 The infusible condition of the silver at the temperature used, and the length and ramifying character of its crystals, render the above experiment difficult to perform, and uncertain in its results I therefore wrought with chloride of lead, using a green glass tube, formed as in Pl VI, *Fig 17* A weighed platina wire was fused into the bottom of a small tube, as before described (789) The tube was then bent to an angle, at about half an inch distance from the closed end, and the part between the angle and the extremity being softened, was forced upward, as in the figure, so as to form a bridge, or rather separation, producing two little depressions or basins *a*, *b*, within the tube This arrangement was suspended by a platina wire, as before, so that the heat of a spirit-lamp could be applied to it, such inclination being given to it as would allow all air to escape during the fusion of the chloride of lead A positive electrode was then provided by bending up the end of a platina wire into a knot, and fusing about twenty grains of metallic lead on to it, in a small closed tube of glass, which was afterwards broken away Being so furnished, the wire with its lead was weighed, and the weight recorded

815 Chloride of lead was now introduced into the tube, and carefully fused The leaded electrode was also introduced after which the metal, at its extremity, soon melted In this state of things the tube was filled up to *c* with melted chloride of lead, the end of the electrode to be rendered negative was in the basin *b*, and the electrode of melted lead was retained in the basin *a*, and, by connexion with the proper conducting wire of a voltaic battery, was rendered positive A volta-electrometer was included in the circuit

816 Immediately upon the completion of the communication with the voltaic battery, the current passed, and decomposition proceeded No chlorine was evolved at the positive electrode but as the fused chloride was transparent, a button of alloy could be observed gradually forming and increasing in size at *b*, whilst the lead at *a* could also be seen gradually to diminish After a time, the experiment was stopped the tube allowed to cool and broken open the wires, with their buttons, cleaned and weighed and their change in weight compared with the indication of the volta-electrometer

817 In this experiment the positive electrode had lost just as much lead as the negative one had gained (795), and the loss and gain were very nearly the equivalents of the water decomposed in the volta-electrometer, giving for lead the number 101 5 It is therefore evident, in this instance, that causing a *strong affinity or no affinity*, for the substance evolved at the *anode*, to be active during the experiment (807), produces no variation in the definite action of the electric current

818 A similar experiment was then made with iodide of lead, and in this manner all confusion from the formation of a periodide avoided (803) No iodine was evolved during the whole action, and finally the loss of lead at the *anode* was the same as the gain at the *cathode* the equivalent number, by comparison with the result in the volta-electrometer, being 103 5

819 Then protochloride of tin was subjected to the electric current in the same manner, using of course, a tin positive electrode No bichloride of tin was now formed (779, 790) On examining the two electrodes, the positive had lost precisely as much as the negative had gained, and by comparison with the volta-electrometer, the number for tin came out 59

820 It is quite necessary in these and similar experiments to examine the interior of the bulbs of alloy at the ends of the conducting wires for occasionally, and especially with those which have been positive, they are cavernous and contain portions of the chloride or iodide used which must be removed before the final weight is ascertained This is more usually the case with lead than tin

821 All these facts combine into, I think, an irresistible mass of evidence, proving the truth of the important proposition which I at first laid down, namely, *that the chemical power of a current of electricity is in direct proportion to the absolute quantity of electricity which passes* (377,

783) They prove, too, that this is not merely true with one substance, as water, but generally with all electrolytic bodies and, further, that the results obtained with any *one substance* do not merely agree amongst themselves, but also with those obtained from *other substances*, the whole combining together into *one series of definite electro-chemical actions* (505) I do not mean to say that no exceptions will appear perhaps some may arise, especially amongst substances existing only by weak affinity, but I do not expect that any will seriously disturb the result announced If, in the well-considered, well-examined, and, I may surely say, well ascertained doctrines of the definite na-

the general conclusion, they ought also to be allowed if they should present themselves at this, the opening of a new view of electro-chemical action not being held up as obstructions to those who may be engaged in rendering that view more and more perfect, but laid aside for a while, in hopes that their perfect and consistent explanation will ultimately appear

822 The doctrine of *definite electro-chemical action* just laid down, and, I believe, established leads to some new views of the relations and classifications of bodies associated with or subject to this action Some of these I shall proceed to consider

823 In the first place, compound bodies may be separated into two great classes, namely, those which are decomposable by the electric current, and those which are not of the latter, some are conductors, others non-conductors, of voltaic electricity[1] The former do not depend for their decomposability upon the nature of their elements only, for, of the same two elements, bodies may be formed, of which one shall belong to one class and another to the

have before described (394), for that law does not extend to the many compound fusible substances that are excluded from this class I propose to call bodies of this, the decomposable class, *electrolytes* (664)

[1] I mean here by *voltaic electricity* merely electricity from a most abundant source but having very small intensity

824 Then, again, the substances into which these divide, under the influence of the electric current, form an exceedingly important general class They are combining bodies, are directly associated with the fundamental parts of the doctrine of chemical affinity and have each a definite proportion, in which they are always evolved during electrolytic action I have proposed to call these bodies generally *ions*, or particularly *anions* and *cations*, according as they appear at the *anode* or *cathode* (665), and the numbers representing the proportions in which they are evolved *electro-chemical equivalents* Thus hydrogen, oxygen, chlorine, iodine, lead, tin are *ions*, the three former are *anions* the two metals are *cations*, and 1, 8, 36, 125, 104, 58, are their *electro-chemical equivalents* nearly

825 A summary of certain points already ascertained respecting *electrolytes*, *ions* and

pass to either of the electrodes, and will be perfectly indifferent to the passing current, unless it be itself a compound of more elementary

&c)

827 ii If one *ion* be combined in right pro-

the *cathode*, of the decomposing body (530, 542, 547)

828 iii If, therefore, an *ion* pass towards one of the electrodes, another *ion* must also be passing simultaneously to the other electrode, although, from secondary action, it may not make its appearance (743)

829 iv A body decomposable directly by the electric current, i e, an *electrolyte*, must consist of two *ions*, and must also render them up during the act of decomposition

not multiples

831 vi A body not decomposable when alone, as *boracic acid, is not directly decomposable* by the electric current when in combination (780) It may act as an *ion* going wholly to the *anode or cathode, but does not yield up its elements*, except occasionally by a secondary action Perhaps it is superfluous for me to point out that this proposition has *no relation* to such cases as that of water, which, by the presence of other bodies, is rendered a better conductor of electricity, and *therefore* is more freely decomposed.

832 vii The nature of the substance of which the electrode is formed, provided it be a conductor, causes no difference in the electro-decomposition, either in kind or degree (807, 813) but it seriously influences, by secondary action (744), the state in which the *ions* finally appear Advantage may be taken of this principle in combining and collecting such *ions* as, if evolved in their free state, would be unmanageable.[1]

833 viii A substance which, being used as the electrode, can combine with the *ion* evolved *against it*, is also, I believe, an *ion*, and combines, in such cases, in the quantity represented by its *electro-chemical equivalent* All the experiments I have made agree with this view, and it seems to me, at present, to result as a necessary consequence Whether, in the secondary *actions that take place, where the ion* acts, not upon the matter of the electrode, but on that which is around it in the liquid (744), the same consequence follows, will require more extended investigation to determine

834 ix Compound *ions* are not necessarily composed of electro-chemical equivalents of simple *ions* For instance, sulphuric acid boracic acid, phosphoric acid, are *ions*, but not *electrolytes*, i e , not composed of electro-chemical equivalents of simple *ions*

835 x Electro-chemical equivalents are always consistent i e , the same number which represents the equivalent of a substance A when it is separating from a substance B, will also represent A when separating from a third substance C Thus, 8 is the electro-chemical equivalent of oxygen, whether separating from hydrogen, or tin, or lead, and *103.5 is the electro-chemical equivalent of* lead, whether separating from oxygen, or chlorine, or iodine

836 xi Electro-chemical equivalents coincide, and are the same with ordinary chemical equivalents

837 By means of experiment and the preceding propositions, a knowledge of *ions* and their electro-chemical equivalents may be obtained in various ways

838 In the first place, they may be determined directly, as has been done with hydrogen, oxygen, lead, and tin, in the numerous experiments already quoted

839 In the next place, from propositions ii and iii, may be deduced the knowledge of many other *ions*, and also their equivalents When chloride of lead was decomposed, platina being used for both electrodes (395), there could remain no more doubt that chlorine was passing to the *anode*, although it combined with the platina there, than when the positive electrode being of plumbago (794), allowed its evolution *in the free state neither could there*, in either case, remain any doubt that for every 103 5 parts of lead evolved at the *cathode*, 36 parts of *chlorine were evolved at the anode*, for the remaining chloride of lead was unchanged So also, when in a metallic solution one volume of *oxygen or a secondary compound containing* that proportion, appeared at the *anode*, no doubt could arise that hydrogen, equivalent to *two volumes, had been determined to the cathode*, although, by a secondary action, it had been employed in reducing oxides of lead, copper, or other metals, to the *metallic state* In this manner, then, we learn from the experiments already described in these *Researches*, that chlorine, iodine, bromine, *fluorine*, calcium, potassium, strontium, magnesium, manganese, &c , are *ions*, and that their *electro-chemical equivalents are the same as their ordinary chemical equivalents*

840 Propositions iv and v extend our means of gaining information *For if a body of known* chemical composition is found to be decomposable, and the nature of the substance evolved as a primary or even a secondary *result* (743, 777) at one of the electrodes, be ascertained, the electro-chemical equivalent of that body may be deduced from the known *constant composition* of the substance evolved Thus when fused protiodide of tin is decomposed by the voltaic current (804), the *conclusion* may be drawn, that both the iodine and tin are *ions*,

[1] It will often happen that the electrodes used may be of such a nature as with the fluid in which they are immersed to produce an electric current, either according with or opposing that of the voltaic arrangement used, and in this way or by direct chemical action may sadly disturb the results Still in the midst of all these confusing effects, the electric current, which *actually passes in any direction* through the body suffering decomposition, will produce its own definite electrolytic action.

and that the proportions in which they combine in the fused compound express their electro-chemical equivalents Again, with respect to the fused iodide of potassium (805), it is an electrolyte and the chemical equivalents will also be the electro-chemical equivalents

841 If proposition viii sustain extensive experimental investigation, then it will not only help to confirm the results obtained by the use of the other propositions, but will give abundant original information of its own

842 In many instances, the *secondary results*

lead, and, as far as I have gone, in other protosalts subjected to the reducing action of the nascent hydrogen at the *cathode*, the metal precipitated has been in the same quantity as if it had been a primary product (provided no free hydrogen escaped there), and therefore gave accurately the number representing its electro-chemical equivalent

843 Upon this principle it is that secondary results may occasionally be used as measurers of the volta-electric current (706, 740), but

precipitated metal crystallize across the solution and touch the positive electrode, similar vitiated results are obtained I expect to find in some salts, as the acetates of mercury and zinc, solutions favourable for this use

number of cases, without using too much liberty towards the due severity of scientific research The series of numbers representing electro-chemical equivalents must, like those expressing the ordinary equivalents of chemically acting bodies, remain subject to the continual correction of experiment and sound reasoning

ular account of this class of bodies Looking forward to such a table as of extreme utility (if well constructed) in developing the intimate relation of ordinary chemical affinity to electrical actions, and identifying the two, not to the imagination merely, but to the conviction of the senses and a sound judgement, I may be allowed to express a hope, that the endeavour will always be to make it a table of *real*, and not *hypothetical*, electro chemical equivalents for we shall else overrun the facts, and lose all sight and consciousness of the knowledge lying directly in our path

846 The equivalent numbers do not profess to be exact, and are taken almost entirely from the chemical results of other philosophers in whom I could repose more confidence, as to these points than in myself

847 TABLE OF IONS

Anions

Oxygen	8	Phosphoric acid	35 7
Chlorine	35 5	Carbonic acid	22
Iodine	126	Boracic acid	24
Bromine	78 3	Acetic acid	51
Fluorine	18 7	Tartaric acid	66
Cyanogen	26	Citric acid	58
Sulphuric acid	40	Oxal c acid	36
Selenic acid	64	Sulphur (?)	16
N tric acid	54	Selenium (?)	
Chloric acid	75 5	Sulpho-cyanogen	

Cations

Hydrogen	1	Mercury	200
Potassium	39.2	Silver	108
Sodium	23.3	Platina	98 6?
Lithium	10	Gold	(?)
Barium	68 7		
Strontium	43 8	Ammonia	17
Calcium	20.5	Potassa	47 2
Magnesium	12 7	Soda	31 3
Manganese	27 7	Lithia	18
Zinc	32 5	Baryta	76 7
Tin	57 9	Strontia	51 8
Lead	103 5	Lime	28 5
Iron	28	Magnes a	20 7
Copper	31 6	Alumina	(?)
Cadmium	55 8	Protoxides generally	
Cerium	46	Quinia	171 6
Cobalt	29 5	Cinchona	160
Nickel	29 5	Morphia	290
Antimony	64 6?	Vegeto-alkalies generally	
Bismuth	71		

848 This table might be further arranged into groups of such substances as either act with, or replace, each other Thus, for instance,

indeed little or no doubt that,

trical relations of the particles of matter come

to be closely examined, this division must be made The simple substances, with cyanogen, sulpho-cyanogen, and one or two other compound bodies, will probably form the first group, and the acids and bases, with such analogous compounds as may prove to be *ions*, the second group Whether these will include all *ions*, or whether a third class of more complicated results will be required, must be decided by future experiments

849 It is *probable* that all our present elementary bodies are *ions*, but that is not as yet certain. There are some, such as carbon, phosphorus, nitrogen, silicon, boron, aluminium, the right of which to the title of *ion* it is desirable to decide as soon as possible There are also many compound bodies, and amongst them alumina and silica, which it is desirable to class immediately by unexceptionable experiments It is also *possible*, that all combinable bodies, compound as well as simple, may enter into the class of *ions*, but at present it does not seem to me probable Still the experimental evidence I have is so small in proportion to what must gradually accumulate around, and bear upon, this point, that I am afraid to give a strong opinion upon it

850 I think I cannot deceive myself in considering the doctrine of definite electro-chemical action as of the utmost importance It touches by its facts more directly and closely than any former fact, or set of facts, have done, upon the beautiful idea, that ordinary chemical affinity is a mere consequence of the electrical attractions of the particles of different kinds of matter, and it will probably lead us to the means by which we may enlighten that which is at present so obscure, and either fully demonstrate the truth of the idea, or develop that which ought to replace it

851 A very valuable use of electro-chemical equivalents will be to decide, in cases of doubt, what is the true chemical equivalent, or definite proportional, or atomic number of a body, for I have such conviction that the power which governs electro-decomposition and ordinary chemical attractions is the same and such confidence in the overruling influence of those natural laws which render the former definite, as to feel no hesitation in believing that the latter must submit to them also Such being the case, I can have no doubt that, assuming hydrogen as 1, and dismissing small fractions for the simplicity of expression, the equivalent number or atomic weight of oxygen is 8, of chlorine 36, of bromine 78 4, of lead 103 5, of tin 59, &c, notwithstanding that a very high authority doubles several of these numbers.

§ 13 *On the Absolute Quantity of Electricity Associated with the Particles or Atoms of Matter*

852 The theory of definite electrolytical or electro-chemical action appears to me to touch immediately upon the *absolute quantity* of electricity or electric power belonging to different bodies It is impossible, perhaps, to speak on this point without committing oneself beyond what present facts will sustain, and yet it is equally impossible, and perhaps would be impolitic, not to reason upon the subject Although we know nothing of what an atom is yet we cannot resist forming some idea of a small particle, which represents it to the mind and though we are in equal, if not greater, ignorance of electricity, so as to be unable to say whether it is a particular matter or matters or mere motion of ordinary matter, or some third kind of power or agent, yet there is an immensity of facts which justify us in believing that the atoms of matter are in some way endowed or associated with electrical powers, to which they owe their most striking qualities, and amongst them their mutual chemical affinity As soon as we perceive, through the teaching of Dalton, that chemical powers are, however varied the circumstances in which they are exerted, definite for each body, we learn to estimate the relative degree of force which resides in such bodies and when upon that knowledge comes the fact, that the electricity, which we appear to be capable of loosening from its habitation for a while, and conveying from place to place, *whilst it retains its chemical force*, can be measured out, and being so measured is found to be *as definite in its action* as any of *those portions* which, remaining associated with the particles of matter, give them their *chemical relation*, we seem to have found the link which connects the proportion of that we have evolved to the proportion of that belonging to the particles in their natural state

853 Now it is wonderful to observe how small a quantity of a compound body is decomposed by a certain portion of electricity Let us, for instance, consider this and a few other points in relation to water *One grain of* water, acidulated to facilitate conduction, will require an electric current to be continued for three minutes and three-quarters of time to effect its decomposition, which current must be powerful enough to retain a platina wire $\frac{1}{104}$ of

an inch in thickness[1] red hot in the air during the whole time and if interrupted anywhere by charcoal points will produce a very brilliant and constant star of light If attention be paid to the instantaneous discharge of electricity of tension as illustrated in the beautiful experiments of Mr Wheatstone[2] and to what I have said elsewhere on the relation of common and voltaic electricity (371 375) it will not be too much to say that this necessary quantity of electricity is equal to a very powerful flash of lightning Yet we have it under perfect command can evolve direct and employ it at pleasure and when it has performed its full work of electrolyzation it has only separated the elements of *a single grain of water*

854 On the other hand the relation between the conduction of the electricity and the decomposition of the water is so close that one cannot take place without the other If the [illegible]

[illegible]

mate and inseparable

855 Considering this close and twofold relation namely that without decomposition transmission of electricity does not occur and, that for a given definite quantity of electricity passed an equally definite and constant quantity of water or other matter is decomposed considering also that the agent, which is electricity is simply employed in overcoming electrical powers in the body subjected to its action it seems a probable and almost a natural consequence that the quantity which passes

[1] I have not stated the length of wire used be [illegible]

[illegible]

nearly uniform

[2] *Literary Gazette* 1833 March 1 and 8 *Philosophical Magazine* 1833 p 204 *L Institut* 1833 p 261

is the *equivalent* of and therefore equal to, that of the particles separated i e that if the electrical power which holds the elements of a grain of water in combination or which makes a grain of oxygen and hydrogen in the right proportions unite into water when they are made to combine could be thrown into the condition of *a current* it would exactly equal the current required for the separation of that grain of wa[illegible]

[illegible]

facts which can be brought to bear on this point To illustrate this I must say a few words on the voltaic pile[3]

857 Intending hereafter to apply the results given in this and the preceding series of *Re*[illegible]

[illegible]

source

858 Those bodies which being interposed [illegible]

[illegible]

parts we have *the two conditions inseparable in such bodies as these*, namely, the passing of a current, and decomposition, and thus is as true of the cells in the battery *as of the water cell*, for no voltaic battery has as yet been constructed in which the chemical action is only that of combination *decomposition is always included*, and is, I believe, an essential chemical part

859 But the difference in the two parts of the connected battery, that is, the decomposition or experimental cell, and the acting cells, is *simply this In the former* we *urge the current through*, but it, apparently of necessity, is accompanied by decomposition in the latter we cause decompositions by *ordinary chemical* actions (which are, however, themselves electrical), and, as a consequence, have the electrical current and as the decomposition dependent upon the current is definite in the former case *so is the current associated with the* decomposition also definite in the latter (862, &c)

860 Let us apply this in support of what I have surmised respecting the enormous electric power of each particle or atom of matter (856) I showed in a former series of these *Researches* on the relation by measure of common *and voltaic electricity, that two wires, one of* platina and one of zinc, each one-eighteenth of an inch in diameter placed five-sixteenths of an inch apart, and immersed to the depth of five-eighths of an inch in acid, consisting of one *drop of oil of vitriol and four ounces of distilled* water at a temperature of about 60° Fahr, and connected at the other extremities by a copper wire eighteen feet long, and one-eighteenth of an inch in thickness, yielded as much electricity in little more than three seconds of time as a Leyden battery charged by thirty turns of a very large and powerful plate electric machine in full action (371) This quantity, though *sufficient if passed at once through the head of a* rat or cat to have *killed* it, as by a flash of lightning, was evolved by the mutual action of so small a portion of the zinc wire and water in contact *with it, that the loss of weight sustained* by either would be inappreciable by our most delicate instruments and as to the water which could be decomposed by that current, it must have been insensible in quantity, for no trace of hydrogen appeared *upon the surface* of the platina during those three seconds

861 What an enormous quantity of electricity, therefore, is required for the decomposition of a single grain of water! We have already seen that it must be in quantity *sufficient to* sustain a platina wire $\frac{1}{104}$ of an inch in thickness, red hot, in contact with the air, for three minutes and three quarters (853), a quantity *which is almost infinitely greater than that* which could be evolved by the little standard voltaic arrangement to which I have just referred (860, 371) I have endeavoured to make a comparison by the loss of weight of such a wire in a given time in such an acid, according to a principle and experiment to be almost immediately described (862), but the proportion is *so high that I am almost afraid to mention* it It would appear that 800,000 such charges of the Leyden battery as I have referred to above, *would be necessary to supply electricity* sufficient to decompose a single grain of water, or, if I am right, to equal the quantity of electricity which is naturally associated with the elements of that grain of water, endowing them *with their mutual chemical affinity*

862 In further proof of this high electric condition of the particles of matter, and *the identity as to quantity of that belonging to them with that necessary for their separation*, I will describe an experiment of great simplicity but extreme beauty, when viewed in relation to the evolution of an electric current and its *decomposing powers*

863 A dilute sulphuric acid, made by adding about one part by measure of oil of vitriol to thirty parts of water, will act energetically upon a piece of zinc plate in its ordinary *and simple state* but, as Mr *Sturgeon* has shown[1] not at all, or scarcely so, if the surface of the metal has in the first instance been amalgamated, yet the amalgamated zinc will act powerfully with platina as an electromotor, hydrogen being evolved on the surface of the latter metal, as the zinc is oxidized and dissolved The amalgamation is best effected by sprinkling *a few drops of mercury* upon the surface *of the zinc, the latter being moistened with the* dilute acid, and rubbing with *the fingers or tow* so as to extend the liquid metal over the whole of the surface Any mercury in excess, forming *liquid drops upon the zinc*, should be wiped off[2]

864 Two plates of zinc thus amalgamated were dried and accurately weighed, one, which we will call A, weighed 163 1 grains the other, to be called B, weighed 148 3 grains They were

[1] *Recent Experimental Researches* &c 1830 p 74, &c

[2] The experiment may be made with pure zinc, which, as chemists well know, is but slightly acted upon by dilute sulphuric acid in comparison with ordinary zinc which during the action is subject to an infinity of voltaic actions See De la Rive on this subject *Bibliothèque Universelle*, 1830 p. 391

nearly the same length, but about three times as wide as the zinc plates, was put up into this jar The zinc plate A was also introduced into the jar, and brought in contact with the platina and at the same moment the plate B was put into the acid of the trough, but out of contact with other metallic matter

865 Strong action immediately occurred in the jar upon the contact of the zinc and platina plates Hydrogen gas rose from the platina, and was collected in the jar, but no hydrogen or other gas rose from *either* zinc plate In about *ten or twelve* minutes, sufficient hydrogen having been collected, the experiment was stopped, *during its* progress a few small bubbles had ap-

oxidized and dissolved during the experiment

866 The hydrogen gas was next transferred to a water trough and measured, it amounted to 12 5 cubic inches the temperature being 52°, and the barometer 29 2 inches This quantity, corrected for temperature pressure and moisture, becomes 12 15453 cubic inches of dry hydrogen at mean temperature and pressure, which increased by one half for the oxygen

not but happen, that for an equivalent of zinc oxidized an equivalent of water must be decomposed [1]

[1] The acid was left during a night with a small piece of unamalgamated zinc in it for the purpose of

867 But let us observe *how* the water is de-

hydrogen at the *cathode* of the body under de composition and these were in many parts of the experiment above an inch asunder Again, the ordinary chemical affinity was not enough under the circumstances to effect the decom

cause the hydrogen to pass to the *cathode*, I need only refer to the results which I have given (807, 813) to show that the chemical action

tricity which passes

circle, was able to evolve such quantity of electricity in the form of a current as passing through water, should decompose 9 parts or one equivalent of that substance and consid- the definite relations of electricity as de-

because it determines the combining force Or, if we adopt the atomic theory or phraseology, then the atoms of bodies which are equivalents

to each other in their ordinary chemical action have *equal quantities of electricity naturally* associated with them But I must confess I am jealous of the term *atom*; for though it is very easy to talk of atoms, it is very difficult to form a clear idea of their nature, especially when compound bodies are under consideration

870 I cannot refrain from recalling here the beautiful idea put forth, I believe, by Berzelius (703) in his development of his views of the electro-chemical theory of affinity, that the heat and light evolved during cases of powerful combination are the consequence of the electric discharge which is at the moment taking place The idea is in perfect accordance with the view I have taken of the *quantity* of electricity associated with the particles of matter

871 In this exposition of the law of the definite action of electricity, and its corresponding definite proportion in the particles of bodies, I do not pretend to have brought, as yet, every case of chemical or electro-chemical action under its dominion There are numerous considerations of a theoretical nature, especially respecting the compound particles of matter and the *resulting electrical forces which they ought* to possess, which I hope will gradually receive their development and there are numerous experimental cases, as for instance, those of compounds formed by weak affinities, the simultaneous decomposition of water and salts, &c , which still require investigation But whatever the results on these and numerous other points may be, I do not believe that the facts which I have advanced, or even the general laws deduced from them, will suffer any serious change and they are of sufficient importance to justify their publication, though much may yet remain imperfect or undone Indeed, it is the great beauty of our science, CHEMISTRY, that advancement in it, whether in a degree great or small, instead of exhausting the subjects of research, opens the doors to further and more abundant knowledge, overflowing with beauty and utility, to those who will be at the easy personal pains of undertaking its experimental investigation

872 The definite production of electricity (868) in association with its definite action proves, I think, that the current of electricity in the voltaic pile is sustained by chemical decomposition, or rather by chemical action, and *not by contact only* But here, as elsewhere (857), I beg to reserve my opinion as to the real action of contact not having yet been able to make up my mind as to whether it is an exciting cause of the current, or merely necessary to allow of the conduction of electricity, otherwise generated, from one metal to the other

873 But admitting that chemical action is the source of electricity, what an infinitely small fraction of that which is active do we obtain and employ in our voltaic batteries! Zinc and *platina wires, one-eighteenth of an inch in diameter* and about half an inch long, dipped in to dilute sulphuric acid, so weak that it is not sensibly sour to the tongue, or scarcely to our most delicate test-papers, will evolve more electricity in one-twentieth of a minute (860) than any man would willingly allow to pass through his body at once The chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunder-storm (868, 861) Nor is it *merely true that the quantity is active* it can be directed and made to perform its full equivalent duty (867, &c) Is there not then great reason to hope and believe that, by a closer *experimental* investigation of the principles which govern the development and action of this subtile agent, we shall be able to increase the power of our batteries, or invent new instruments which shall a thousandfold surpass in energy those which we at present possess?

874 Here for a while I must leave the consideration of the *definite chemical action of electricity* But before I dismiss this series of experimental *Researches*, I would call to mind that, in a former series, I showed the current of electricity was also *definite in its magnetic action* (216, 366, 367, 376, 377), and, though this result was not pursued to any extent, I have no doubt that the success which has attended the development of the chemical effects is not more than would accompany an investigation of the magnetic phenomena

Royal Institution, December 31, 1833

EIGHTH SERIES

§ 14. *On the Electricity of the Voltaic Pile; its Source, Quantity, Intensity, and General Characters* ¶ i. *On Simple Voltaic Circles* ¶ ii. *On the Intensity Necessary for Electrolyzation* ¶ iii *On Associated Voltaic Circles, or the Voltaic Battery* ¶ iv. *On the Resistance of an Electrolyte to Electrolytic Action and on Interpositions* ¶ v. *General Remarks on the Active Voltaic Battery*

RECEIVED APRIL 7, READ JUNE 5, 1834

¶ i *On Simple Voltaic Circles*

875 THE great question of the source of elec-

the truth was somewhere revealed But if in pursuance of this impression he were induced to enter upon the work of collating results and conclusions, he would find such contradictory evidence, such equilibrium of opinion, such variation and combination of theory, as would leave him in complete doubt respecting what he should accept as the true interpretation of

who have made up their minds on the matter, be my apology for entering upon its investigation The views I have taken of the definite action of electricity in decomposing bodies (783), and the *identity of the power so used with the power to be overcome* (855), founded not on a mere opinion or general notion, but on facts which, being altogether new, were to my mind precise and conclusive, gave me, as I conceived, the power of examining the question

in dispelling that which is deceptive in it, and revealing more clearly that which is true, is as useful in his place, and as necessary to the general progress of the science, as he who first broke through the intellectual darkness, and opened a path into knowledge before unknown to man

877 The identity of the force constituting the voltaic current or electrolytic agent, with that which holds the elements of electrolytes together (855), or in other words with chemical affinity, seemed to indicate that the electricity of the pile itself was merely a mode of exertion, or exhibition, or existence of *true chemical action*, or rather of its cause, and I have consequently already said that I agree with those who believe that the *supply* of electricity is due to chemical powers (857)

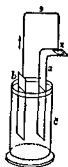
either might be looked upon as the *determining* cause of the current

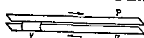
879 I thought it essential to decide this ques-

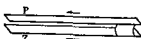
into action (863), seemed

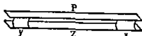
able obstruction in the way of such

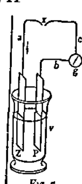
PLATE VII

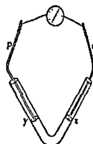

Fig 1

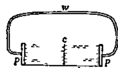

Fig 2

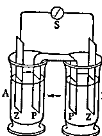

Fig 3

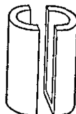

Fig 4

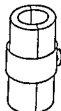

Fig 5

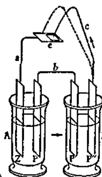

Fig. 6

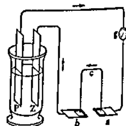

Fig. 7


Fig 8


Fig 9


Fig 10


Fig 12


Fig 13

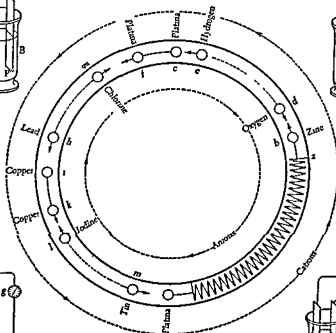
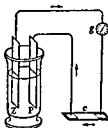
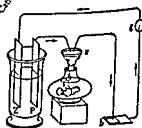


Fig. 11


Fig. 14


Fig. 15

ments, but I remembered the easy decomposability of the solution of iodide of potassium (316), and seeing no theoretical reason, if metallic contact was not *essential*, why true electro-decomposition should not be obtained without it, even in a single circuit, I persevered and succeeded [illegible]

plate of platina, about three inches long and half an inch wide, was fastened to a platina wire, and the latter bent as in the figure, *b* These two pieces of metal were arranged together as delineated, but as yet without the vessel *c*, and its contents, which consisted of dilute sulphuric acid mingled with a little nitric acid At *x* a piece of folded bibulous paper, moistened in a solution of iodide of potassium, was placed on the zinc, and was pressed upon by the end of the platina wire When under these circumstances the plates were dipped in [illegible]

against the end of the platina wire

881 As long as the lower ends of the plates remained in the acid the electric current continued, and the decomposition proceeded at *x* On removing the end of the wire from place to place on the paper, the effect was evidently [illegible]

the *cathode* (663) against the zinc, in proportion to the evolution of iodine at the *anode* Hence the decomposition was perfectly polar, and decidedly dependent upon a current of electricity passing from the zinc through the acid to the platina in the vessel *c*, and back from the platina through the solution to the zinc at the paper *x*

882 That the decomposition at *x* was a true [illegible]

to form at *x*, was shown, in the first place, by removing the vessel *c* and its acid from the plates, when all decomposition at *x* ceased, and in the next by connecting the metals, either in or out of the acid, together, when decomposition of the iodide at *x* occurred but in a *reverse order*, for now alkali appeared against the end of the platina wire, and the iodine passed to the zinc, the current being the contrary of what it was in the former instance, and produced directly by the difference of action of the solution in the paper on the two metals The iodine of course *combined* with the zinc

883 When this experiment was made with *pieces of zinc amalgamated over the whole surface* (863), the results were obtained with equal facility and in the same direction, even when only dilute sulphuric acid was contained in the vessel *c* (Pl VII, *Fig 1*) Whichsoever end of the zinc was immersed in the acid, still the effects were the same so that if, for a moment, the mercury might be supposed to supply the metallic contact, the inversion of the amalgamated piece destroys that objection The use of *unamalgamated zinc* (880) removes all possibility of doubt [1]

884 When, in pursuance of other views (930), the vessel *c* was made to contain a solution of caustic potash in place of acid still the same results occurred Decomposition of the iodide was effected freely, though there was no metallic contact of dissimilar metals, and the current of electricity was in the *same direction* as when acid was used at the place of excitement

885 Even a solution of common salt in the glass *c* could produce all these effects

886 Having made a galvanometer with plat- [illegible]

action

887 If we consider these results generally, [illegible]

[1] The following is a more striking mode of making [illegible]

next place, they show a most extraordinary *mutual relation of the chemical affinities of the fluid which excites* the current, and the fluid *which is decomposed by it*

888 For the purpose of simplifying the consideration, let us take the experiment with amalgamated zinc The metal so prepared exhibits no effect until the current can pass it at the same time introduces no new action, but merely removes an influence which is extraneous to those belonging either to the production or the effect of the electric current under investigation (1000), an influence also which, when present, tends only to confuse the results

889. Let two plates, one of amalgamated zinc and the other of platina, be placed parallel to each other (Pl VII, *Fig 2*), and introduce a drop of dilute sulphuric acid, *y*, between them at one end there will be no sensible chemical action at that spot unless the two plates are connected somewhere else, as at P Z, by a body capable of conducting electricity If that body be a metal or certain forms of carbon, then the current passes, and, as it circulates through the fluid at *y*, decomposition ensues.

890 Then remove the acid from *y*, and introduce a drop of the solution of iodide of potassium at *x* (Pl VII, *Fig 3*) Exactly the same set of effects occur, except that when the metallic communication is made at P Z, the electric current is in the opposite direction to what it was before, as is indicated by the arrows, which show the courses of the currents (667)

891 Now *both* the solutions used are conductors, but the conduction in them is essentially connected with decomposition (858) in a certain constant order, and therefore the appearance of the elements in certain places *shows* in what direction a current has passed when the solutions are thus employed Moreover, we find that when they are used at opposite ends of the plates, as in the last two experiments (889, 890), metallic contact being allowed at the other extremities, the currents are in opposite directions We have evidently, therefore, the power of opposing the actions of the two fluids simultaneously to each other at the opposite ends of the plates, using each one as a conductor for the discharge of the current of electricity, which the other tends to generate, in fact, substituting them for metallic contact, and combining both experiments into one (Pl VII, *Fig 4*) Under these circumstances, there is an opposition of forces the fluid, which brings into play the stronger set of chemical affinities for the zinc, (being the dilute acid), overcomes the force of the other, and determines the formation and direction of the electric current not merely making that current pass through the weaker liquid, but actually reversing the tendency which the elements of the latter have in relation to the zinc and platina if not thus counteracted, and forcing them in the contrary direction to that they are inclined to follow, that its own current may have free course If the dominant action at *y* be removed by making metallic contact there, then the liquid at *x* resumes its power, or if the metals be not brought into contact at *y*, but the affinities of the solution there weakened, whilst those active at *x* are strengthened, then the latter gains the ascendency, and the decompositions are produced in a contrary order

892 Before drawing a *final* conclusion from this mutual dependence and state of the chemical affinities of two distant portions of acting fluids (916), I will proceed to examine more minutely the various circumstances under which the re-action of the body suffering decomposition is rendered evident upon the action of the body, also undergoing decomposition, which produces the voltaic current

893 The use of *metallic contact* in a single pair of plates, and the cause of its great superiority above contact made by other kinds of matter, become now very evident When an amalgamated zinc plate is dipped into dilute sulphuric acid, the force of chemical affinity exerted between the metal and the fluid is not sufficiently powerful to cause sensible action at the surfaces of contact, and occasion the decomposition of water by the oxidation of the metal, although it *is* sufficient to produce such a condition of the electricity (or the power upon which chemical affinity depends) as would produce a current if there were a path open for it (916, 956), and that current would complete the conditions necessary, under the circumstances, for the decomposition of the water

894 Now the presence of a piece of platina touching both the zinc and the fluid to be decomposed, opens the path required for the electricity Its *direct communication* with the zinc is effectual, far beyond any communication made between it and that metal (i e , between the platina and zinc), by means of decomposable conducting bodies, or, in other words, *electrolytes*, as in the experiment already described (891), because, when *they* are used, the chemical affinities between them and the zinc produce a contrary and opposing action to that which is influential in the dilute sulphuric acid.

or if that action be but small, still the affinity of their component parts for each other has to be overcome, for they cannot conduct without suffering decomposition and this decomposition is found *experimentally* to react back upon the forces which in the acid tend to produce the current (904, 910, &c), and in numerous cases entirely to neutralize them Where direct contact of the zinc and platina occurs these obstructing forces are not brought into action, and therefore the production and the circulation of the electric current and the concomitant action of decomposition are then highly favoured

895 It is evident, however, that one of these opposing actions may be dismissed, and yet an electrolyte be used for the purpose of completing the circuit between the zinc and platina immersed separately into the dilute acid, for if, in Pl VII, *Fig 1*, the platina wire be retained in metallic contact with the zinc plate *a*, at *x*, and a division of the platina be made elsewhere, as at *s*, then the solution of iodide placed there, being in contact with platina at both surfaces exerts no chemical affinities for that metal, or if it does, they are equal on both sides Its power

obstacle to be overcome by the affinities exerted in the dilute sulphuric acid

896 This becomes the condition of a single pair of active plates where *metallic contact* is allowed In such cases only one set of opposing affinities are to be overcome by those which are dominant in the vessel *c*, whereas, when metallic contact is not allowed, two sets of opposing affinities must be conquered (894)

897 It has been considered a difficult, and by some an impossible thing, to decompose bodies by the current from a single pair of plates even when it was so powerful as to heat bars of metal red hot, as in the case of Hare's calorimeter, arranged as a single voltaic circuit, or of Wollaston's powerful single pair of metals This difficulty has arisen altogether from the antagonism of the chemical affinity engaged in

perfect accordance, both as to direction and quantity, with the course of those which are

current But I now began to perceive a reason for its failure, and for a fact which I had observed long before (315, 316) with regard to the iodide of potassium, namely, that bodies would differ in facility of decomposition by a given electric current, according to the condition and intensity of their ordinary chemical

having no reference

uid was to be acted upon, the two ends were merely dipped into it if a solution contained

cathode, of the decomposing body

901 *Protochloride of tin*, when fused and placed at *x*, was also readily decomposed, yielding perchloride of tin at the a

tin at the *cathode*

902 Fused chloride of silver, placed at x, was also easily decomposed, chlorine was evolved at the *anode*, and brilliant metallic silver, either in films upon the surface of the liquid, or in crystals beneath, evolved at the *cathode*

903 *Water acidulated with sulphuric acid*, solution of muriatic acid, solution of sulphate of soda, fused nitre, and the fused chloride and iodide of lead were not decomposed by this single pair of plates, excited only by dilute sulphuric acid

904 These experiments give abundant proofs that a single pair of plates can electrolyze bodies and separate their elements They also show in a beautiful manner the direct relation and opposition of the chemical affinities concerned at the two points of action In those cases where the sum of the opposing affinities at x was sufficiently beneath the sum of the acting affinities in i, decomposition took place but in those cases where *they* rose *higher*, *decomposition* was effectually resisted and the current ceased to pass (891)

905 It is however, evident, that the sum of acting affinities in v may be increased by using other fluids than dilute sulphuric acid, in which latter case, as I believe it is merely the affinity

then be decomposed, because of the increased difference between their affinities and the acting affinities thus exalted This expectation was fully confirmed in the following manner

906 A little nitric acid was added to the liquid in the vessel i, so as to make a mixture which I shall call diluted nitro sulphuric acid On repeating the experiments with this mixture, all the substances before decomposed

parently not decomposed by this pair, nor did water acidulated by sulphuric acid seem at first to give way (973)

908 The increase of intensity or power of the current produced by a simple voltaic circle *with the increase of the force of the chemical* action at the exciting place, is here sufficiently evident But in order to place it in a clearer point of view, and to show that the decomposing effect was not at all dependent, in the latter cases, upon the mere capability of evolving *more* electricity, experiments were made in which the quantity evolved could be increased without variation in the intensity of the exciting cause Thus the experiments in which dilute sulphuric acid was used (899) were repeat

new circumstances Then again, where nitro *sulphuric acid was used (906)*, *mere wires of* platina and zinc were immersed in the exciting acid, yet, notwithstanding this change, those bodies were now decomposed which resisted any current tending to be formed by the dilute sulphuric acid For instance, muriatic acid could not be decomposed by a single pair of plates

plates immersed in it, increase the po

if to a weak sulphuric acid a very little nitric acid was added, then the electricity evolved had power to decompose the muriatic acid, evolving chlorine at the *anode* and hydrogen at the *cathode*, even when mere wires of metals were used This mode of increasing the intensity of the electric current, as it excludes the effect dependent upon many pairs of plates or even the effect of making any one acid stronger or weaker, is at once referable to the condition and force of the chemical affinities which are brought into action, and may, both in principle and practice, be considered *as* perfectly distinct from any other mode

909 The direct reference which is thus experimentally made in the simple voltaic circle of the *intensity* of the electric current to the *intensity* of the chemical action going on at the place where the existence and direction of the current is determined, leads to the conclusion that by using selected bodies, as fused chlo- ... which may

als in association with platina, or with each other, which shall differ in the degree of chemical action exerted between them and the exciting fluid or electrolyte, we shall be able to obtain a series of comparatively constant effects due to electric currents of different intensities, which will serve to assist in the construction of a scale competent to supply the means of determining relative degrees of intensity with accuracy in future researches [1]

910 I have already expressed the view which I take of the decomposition in the experimental place, as being the direct consequence of the superior exertion at some other spot of the same kind of power as that to be overcome, and therefore as the result of an antagonism of forces of the *same* nature (891, 904) Those at the place of decomposition have a reaction upon, and a power over, the exerting or determining set proportionate to what is needful to overcome their own power, and hence a curious re-

which are electrolytes in the fluid state cease to be such in the solid form because the attractions of the particles by which they are retained in combination and in their relative position, are then too powerful for the electric current [2] The particles retain their places, and as decomposition is prevented, the transmission of the electricity is prevented also, and al-

pended and ... ted

finities by which the elements in the substance tend to retain their places, they also would supply cases constituting a series of degrees by which to measure the initial intensities of simple voltaic or other currents of electricity, and which, combined with the scale of intensities determined by different degrees of *acting force* (909), would probably include a sufficient set of differences to meet almost every important case where a reference to intensity would be required

tensity These currents were always from a single pair of plates, and may be considered as elementary *voltaic forces*

Iodide of potassium (solution)
Chloride of silver (fused)
Protochloride of tin (fused)
Chloride of lead (fused)
Iodide of lead (fused)
Muriatic acid (solution)
Water, acidulated with sulphuric acid

bodies present in the surrounding fluid, then the affinity resisting decomposition is in part

sity, with the use of electrodes consisting of matter, having more or less affinity for the elements evolved from the decomposing electrolyte, various intermediate degrees may be obtained

915 Returning to the consideration of the source of electricity (878, &c), there is another *proof of the most perfect kind that metallic* contact has nothing to do with the *production* of electricity in the voltaic circuit, and further, that electricity is only another mode of the exertion of chemical forces It is, the production of the *electric spark* before any contact of metals is made, and by the exertion of *pure and unmixed chemical forces* The experiment, which will be described further on (956), consists in obtaining the spark upon making contact between a plate of zinc and a plate of copper plunged into dilute sulphuric acid In order to make the arrangement as elementary as possible, mercurial surfaces were dismissed, and the contact made by a copper wire connected with the copper plate, and then brought to touch a clean part of the zinc plate The electric spark appeared and it must of necessity have existed and passed *before the zinc and the copper were in contact*

916 In order to render more distinct the principles which I have been endeavouring to establish, I will restate them in their simplest form, according to my present belief The electricity of the voltaic pile (856 *note*) is not dependent either in its origin or its continuance upon the contact of the metals with each other (880, 915) It is entirely due to chemical action (882), and is proportionate in its intensity to the intensity of the affinities concerned in its production (908), and in its quantity to the quantity of matter which has been chemically active during its evolution (869) This definite production is again one of the strongest proofs *that the electricity is of chemical origin*

917 As *volta-electro-generation* is a case of mere chemical action, so *volta-electro-decomposition* is simply a case of the preponderance of one set of chemical affinities more powerful in their nature, over another set which are less powerful and if the instance of two opposing sets of such forces (891) be considered, and their mutual relation and dependence borne in mind, there appears no necessity for using, in respect to such cases, any other term than chemical affinity (though that of electricity may be very convenient), or supposing any new agent to be concerned in producing the results, for we may consider that the powers at the two places of action are in direct communion and balanced against each other through the medium of the metals (891), Pl VII, *Fig 4* in a manner analogous to that in which mechanical forces are balanced against each other by the intervention of the lever (1031)

918 *All the facts show us that that power* commonly called chemical affinity, can be communicated to a distance through the metals and certain forms of carbon, that the electric current is only another form of the forces of chemical affinity, that its power is in proportion to the chemical affinities producing it that when it is deficient in force it may be helped by calling in chemical aid the want in the former being made up by an equivalent of the latter, that, in other words, *the forces termed chemical affinity and electricity are one and the same*

919 When the circumstances connected with the production of electricity in the ordinary voltaic circuit are examined and compared, it appears that the source of that agent, always meaning the electricity which circulates and completes the current in the voltaic apparatus and gives that apparatus power and character (947, 996), exists in the chemical action which takes place directly between the metal and the body with which it combines, and not at all in the subsequent action of the substance so produced with the acid present [1] Thus, when zinc, platina, and dilute sulphuric acid are used, it is the union of the zinc with the oxygen of the water which determines the current and though the acid is essential to the removal of the oxide so formed, in order that another portion of zinc may act on another portion of water, it does not, by combination with that oxide, produce any sensible portion of the current of electricity which circulates, for the quantity of electricity is *dependent upon the quantity of zinc oxidized* and in definite proportion to it its *intensity is* in proportion to the intensity of the chemical affinity of the zinc for the oxygen under the circumstances, and is scarcely, if at all, affected by the use of either strong or weak acid (908)

920 Again, if zinc, platina, and muriatic acid are used, the electricity appears to be dependent upon the affinity of the zinc for the chlorine, and to be circulated in exact proportion to the number of particles of zinc and chlorine which unite, being in fact an equivalent to them

[1] Wollaston *Philosophical Transactions* 1801 p.427

921 But in considering this oxidation, or other direct action upon the METAL itself as the cause and source of the electric current, it is of the utmost importance to observe that the oxygen or other body must be in a peculiar condition namely, in the state of *combination* and not only so, but limited still further to such a state of combination and in such proportions as will constitute an *electrolyte* (823) A pair of zinc and platina plates cannot be so arranged

[illegible]

than if the pair of plates were plunged into dilute sulphuric acid for the oxygen is not part of an electrolyte and cannot therefore conduct the forces onwards by decomposition or even as metals do by itself Or if its gaseous state embarrass the minds of some then liquid chlorine may be taken It does not excite a current of electricity through the two plates by combining with the zinc for its particles cannot transfer the electricity active at the point of combination across to the platina It is not a conductor of itself, like the metals nor is it an electrolyte so as to be capable of conduction during decomposition and hence there is simple chemical action at the spot, and no electric current [1]

922 It might at first be supposed that a con

[illegible]

metals They must however be chosen from the metals themselves, for there are no bodies of this kind except those substances and charcoal To decide the matter by experiment I made

[illegible]

wire *p*, *w*, inserted so as to have their ends immersed some depth in the tin the whole was then allowed to cool and the ends *p* and *w* connected with a delicate galvanometer The part of the tube at *x* was now reheated, whilst

the portion *y* was retained cool The galvanometer was immediately influenced by the thermo-electric current produced The heat was steadily increased at *x* until at last the tin and platina combined there an effect which is known

[illegible]

[1] I do not mean to affirm that no traces of electricity [illegible]

can pass in that one line, and, whilst it passes, can consist with and favour the renewal of the conditions upon the surface of the zinc, which at first determined both the combination and circulation Hence the continuance of the action there, and the continuation of the current It therefore appears quite as essential that there should be an electrolyte in the circuit, in order that the action may be transferred forward, in a *certain constant direction*, as that there should be an oxidizing or other body capable of acting directly on the metal, and it also

be one of the *ions* of the electrolyte used Whether the voltaic arrangement be excited *by solution of acids, or alkalies, or sulphurets*, or by fused substances (476), this principle has always hitherto, as far as I am aware, been an *anion* (943) and I anticipate, from a consideration of the principles of electric action, that it must of necessity be one of that class of bodies

925 If the action of the sulphuric acid used in the voltaic circuit be considered, it will be found incompetent to produce any sensible portion of the electricity of the current by its combination with the oxide formed, for this simple reason, it is deficient in a most essential condition, it forms no part of an electrolyte, nor is it in relation with any other body present in the solution which will permit of the mutual transfer of the particles and the consequent transfer of the electricity It is true that, as the plane at which the acid is dissolving the oxide of zinc formed by the action of the water is in contact with the metal zinc, there seems no difficulty in considering how the oxide there could communicate an electrical state, proportionate to its own chemical action on the acid, to the metal, which is a conductor, without decomposition But on the side of the acid there is no substance to complete the circuit the water, as water, cannot conduct it or at least only so small a proportion that it is merely an incidental and almost inappreciable effect (970), and it cannot conduct it as an electrolyte, because

926 This view of the secondary character of the sulphuric acid as an agent in the production of the voltaic current, is further confirmed by the fact that the current generated and transmitted is directly and exactly proportional to the quantity of water decomposed and the quantity of zinc oxidized (868, 991), and is the same as that required to decompose the same quantity of water As, therefore, the decomposition of the water shows that the electricity has passed by its means, there remains no other electricity to be accounted for or to be referred to any action other than that of the zinc and the water on each other

a (*Pl VII, Fig 7*), *be supposed to be a dry* ox acid, and *b* a dry base, in contact at *c* and in electric communication at their extremities by plates of platina *p p*, and a platina wire *w* If this acid and base were fluid and combination took place at *c*, with an affinity ever so vigor-

duct without being decomposed, for they are either electrolytes or else insulators, under all

either of *a* or *b* to separate, but only such as would make the two bodies combine together as a whole, the point of action is, therefore, insulated, the action itself local (921, 947), and no current can be formed

928 If the acid and base be dissolved in water, then it is possible that a small portion of the electricity due to chemical action may be conducted by the water without decomposition (966, 984), but the quantity will be so small as to be utterly disproportionate to that due to the equivalents of chemical force will be merely incidental, and, as it does not involve the essential principles of the voltaic pile, it forms no part of the phenomena at present under investigation [1]

929 If for the oxacid a hydracid be substituted (927)—as one analogous to the muriatic,

[1] It will I trust be fully understood that in these investigations I am not professing to take an account of every small incidental or barely possible effect, ... of the electric

for instance—then the state of things changes altogether, and a current due to the chemical action of the acid on the base is possible But now both the bodies act as electrolytes, for it is only one principle of each which combine mutually—as for instance the chlorine with

ly laid down

930 This view of the oxidation of the metal, or other *direct* chemical action upon it, being the sole cause of the production of the electric current in the ordinary voltaic pile, is supported by the effects which take place when alkaline or sulphuretted solutions (931, 943) are used for the electrolytic conductor instead of dilute sulphuric acid It was in elucidation

made

931 Advantage was then taken of the more favourable condition offered, when metallic contact is allowed (895), and the experiments upon the decomposition of bodies by a single

All the effects occurred as before the gal vanometer was deflected, the decompositions of the solutions of iodide of potassium nitrate of silver, muriatic acid and sulphate of soda ensued at x, and the places where the evolved principles appeared as well as the deflection of the galvanometer indicated a current in the *same direction* as when acid was in the vessel v, i e, from the zinc through the solution to the

produced If a plate of amalgamated zinc be put into a solution of potassa it is not sensibly acted upon, but if touched in the solution by a plate of platina, hydrogen is evolved on the surface of the latter metal, and the zinc is oxidized exactly as when immersed in dilute sulphuric acid (863) I accordingly repeated the experiment before described with weighed plates of zinc (864, &c), using however solu-

zinc, still I found that the hydrogen evolved at the platina plate was the equivalent of the metal oxidized at the surface of the zinc Hence the whole of the reasoning which was applicable in the former instance applies also here the current being in the same direction, and its decomposing effect in the same degree, as if acid instead of alkali had been used (868)

933 The proof, therefore appears to me complete that the combination of the acid with the oxide, in the former experiment, had nothing to do with the production of the electric current for the same current is here produced when the action of the acid is absent and the reverse action of an alkali is present I think it cannot be supposed for a moment that the alkali acted chemically as an acid to the oxide

sort, the direction of the electricity was constant, and its quantity also directly proportional to the water decomposed or the zinc oxidized There are reasons for believing that acids and alkalies when in contact with metals upon which they cannot act directly, still have a power of influencing their attractions for

tion of the current

934 The experiments were then varied by

improved in that power by adding sulphate of

935 In order to put the equal and similar action of acid and alkali to stronger proof, arrangements were made as in Pl VII, *Fig 8*, the glass vessel A contained dilute sulphuric acid, the corresponding glass vessel B solution of potassa, P P was a plate of platina dipping into both solutions, and Z Z two plates of amalgamated zinc connected with a delicate gal vanometer When these were plunged at the same time into the two vessels there was gen *erally a first feeble effect, and that in favour of* the alkali i e , the electric current tended to pass through the vessels in the direction of the arrow, being the reverse direction of that which the acid in A would have produced alone but the effect instantly ceased, and the action of the plates in the vessels was so equal, that being contrary because of the contrary position of the plates, no permanent current resulted

936 Occasionally a zinc plate was substituted for the plate P P, and platina plates for the plates Z Z, but this caused no difference in the results nor did a further change of the middle plate to copper produce any alteration

937 As the opposition of electro-motive pairs of plates produces results other than those due to the mere difference *of their* independent actions (1011, 1045) I devised another f apparatus in which th l alkal

ter, and at least a of an inch in thickness was cut down the *middle into halves (Pl VII Fig 9) A broad* brass ring larger in diameter than the cup, was supplied with a screw at one side so that when the two halves of the cup were within the ring and the screw was made to press tightly against the glass, the cup *held* any *fluid* put into it Bibulous paper of different degrees of *permeability* was then *cut into pieces of such* a size as to be easily introduced between the loosened halves of the cup, and served when the latter were tightened again to form a porous division *down* the middle of the cup, *sufficient to keep any two fluids on opposite sides* of the paper from mingling except very slowly, and yet allowing them to act *freely* as one *electrolyte* The two spaces thus produced I will call the cells A and B (Pl

c ation of fl amongst themselves and to each other By combining its use with that of *the galvanometer,* it is easy to ascertain the relation of one metal with two fluids, or of two metals with one fluid or of two metals and two fluids upon each other

938 Dilute sulphuric acid, sp gr 1.25, was put *into the cell A, and a strong solution of* caustic potassa into the cell B they mingled slowly through the paper, and at last a thick crust of sulphate of potassa formed on the side of the paper next to the alkali A plate of clean platina was put into each cell and connected with a delicate galvano current

uce a current nor combination of the h more off

mo am , a strong electric *current* was produced But, whether the zinc were in the acid whilst the platina was in the alkali or whether the reverse order were chosen the electric current was always from the zinc through the electrolyte to the platina, and back through the galvanometer to the zinc the current seeming *to be strongest when the* zinc was in the alkali and the platina in the acid

940 In these *experiments, therefore* the acid seems to have no power over the alkali but to be rather inferior to it in force Hence there is no reason to suppose that the combination of the oxide formed with the acid around it has any direct influence in producing *the electricity* evolved, the whole of which appears to be due to the *oxidation of the* metal (919)

941 The alkali, in fact is superior to the acid in bringing a metal into what is called the positive state for if plates of the same metal as zinc, tin, lead or copper be used both in the acid or alkali, *the electric current is from the* alkali across the cell to the acid, and back through the *galvanometer* to the alkali as Sir Humphry Davy formerly stated [1] This current is so powerful, that if amalgamated zinc or tin, or lead be used, the metal in *the acid* evolves hydrogen the moment it is placed in *communication* with that *in the alkali* not from any direct action of the acid upon it for if the contact be broken the action ceases, but because it is powerfully negative with regard to the metal in the alkali

942 The superior

[1] *Chemical Philosophy* p. 149 or *Philosophical Transactions* 1826 p 403

negative Whichsoever is in the alkali is oxidized, whilst that in the acid remains in the metallic state, as far as the electric current is concerned

943 When sulphuretted solutions are used (930) in illustration of the assertion, that it is the chemical action of the metal and one of the ions of the associated electrolyte that produces all the electricity of the voltaic circuit, the proofs are still the same Thus, as Sir Humphry Davy[1] has shown, if iron and copper be plunged into dilute acid, the current is from the iron

[illegible]

[illegible] current, but both of these are *ions*, existing as such in the electrolyte, which is at the same moment *suffering decomposition*, and, *what is* [illegible]

[illegible] might have been previously chosen as that which should be used to throw the voltaic circle into activity

[illegible]

metal, was put into pure water, and connected through the *galvanometer with a plate of platina* in the same water There was immediately an electric current from the amalgam through the electrolyte to the platina. This must have been due to the oxidation only of the metal, for there was neither acid nor alkali to combine [illegible]

[illegible]

the circuit in the form of apparatus already de-[illegible]

[illegible]

946 There is no point in electrical science which seems to me of more importance than the state of the metals and the electrolytic conductor in a simple voltaic circuit *before and at the moment when metallic contact is first completed* If clearly understood, I feel no doubt it would supply us with a direct key to the laws under which the great variety of voltaic excitements, *direct and incidental, occur, and open* out new fields of research for our investigation[*]

947 We seem to have the power of deciding to a certain extent in numerous cases of chemical affinity, (as of zinc with the oxygen of water, &c, &c) which of *two modes of action of the attractive power* shall be exerted (996) In the one mode we can transfer the power onwards, and make it produce elsewhere its equivalent of action (867, 917), in the other it is not transferred, but exerted wholly at the spot The first is the case of volta-electric excitation, the other ordinary chemical affinity but both are chemical actions and due to one force or principle

948 *The general circumstances of the former* mode occur in all instances of voltaic currents, but may be considered as in their perfect condition and then free from those of the second mode in some only of the cases as in those of plates of zinc and platina in solution of potassa, or of amalgamated zinc and platina in dilute sulphuric acid

949 Assuming it sufficiently proved by the preceding experiments and considerations, that the electro-motive action depends, when zinc, platina, and dilute sulphuric acid are used, [illegible]

power enough, under the circumstances, to take [illegible]

[illegible]

[1] *Elements of Chemical Philosophy* p 148

[*] In connexion with this part of the subject refer now to Series XI 1164 Series XII 1343–1358 and Series XIII 1621 &c.—*Dec. 1838*

each other then a series of decompositions and

platina and the place where the zinc is active *these intervening particles being evidently in* close dependence upon and relation to each other The zinc forms a direct compound with

fresh surface of zinc is presented to the water to renew and repeat the action

water by the dominant attraction of the zinc for the oxygen is then transferred in a most extraordinary manner through the two metals, so as to re-enter upon the circuit in the electrolytic conductor which unlike the metals in that respect cannot convey or transfer it without suffering decomposition or rather probably it is exactly balanced and neutralized by the force wh ch at the same moment completes the combination of the zinc with the oxygen of the water The forces in fact of the two parti

to me impossible to resist the idea that it must be preceded by a *state of tension* in the fluid and between the fluid and the zinc the *first consequence* of the affinity of the zinc for the oxygen of the water

951 I have sought carefully for indications of a state of tension in the electrolytic conduc

long one inch and a ... w de and six inches

with calico, so that when made active by connexion with a battery upon any solution in the

cell the bubbles of gas rising from them did not obscure the central parts of the liquid

952 A saturated solution of sulphate of soda was put into the cell and the electrodes connected with a battery of 150 pairs of 4-inch plates the current of electricity was conducted across the cell so freely that the discharge was as good as if a wire had been used A ray of polarized light was then transmitted through this solution directly across the course of the electric current and examined by an analysing

reversed during the observations not the slightest trace of action on the ray could be perceived

953 The large electrodes were then removed and others introduced which fitted the *ends of the cell* In each a slit was cut so *as to allow* the light to pass The course of the polarized ray was now parallel to the current or in the direction of its axis (517) but still no effect under any circumstances of contact or disunion could be perceived upon it

954 A strong solution of nitrate of lead was employed instead of the sulphate of soda but no effects could be detected

955 Thinking it possible that the discharge of the electric forces by the successive decompositions and recompositions of the particles of ... therefore

when fluid was a perfect insulator when so ... the form of a glass

and sometimes even with the electric machine for the advantage of the much higher intensity then obtained I passed a polarized *ray across* it in various directions as before but could not ... of act on upon

tension can in this way be rendered evident

956 There is however one beautiful experimental proof of a state of tension acquired by the metals and the electrolyte before the electric [illegible]

as a cause of action I took a voltaic apparatus consisting of a single pair of large plates name- [illegible]

[illegible] the two plates

957 Being thus arranged there was no chemical action whilst the plates were not connected On *making* the connexion a spark was obtained [2] and the solution was immediately decomposed On breaking it the usual spark was obtained and the decomposition ceased In this case it is evident that the first spark must have occurred before metallic contact was made for it passed through an interval of air, and also that it must have tended to pass before the electrolytic action began for the latter could not take place until the current passed and the current could not pass before the spark appeared Hence I think there is sufficient proof that as it is the zinc and water which by their mutual action produce the electricity of this apparatus so these by their first contact with each other were placed in a state of powerful tension (951) which though it could not produce the actual decomposition of the water was able to make a spark of electricity pass between the zinc and a fit discharger as soon as the interval was rendered sufficiently small The experiment demonstrates the direct production of the electric spark from pure chemical forces

958 There are a few circumstances connected with the production of this spark by a single pair of plates which should be known to ensure success to the experiment [3] When the [illegible]

either mercurial surface then the first spark was often feeble and often failed the breaking spark however continuing very constant and bright When a little water was put over the mercury the spark was greatly diminished in brilliancy but very regular both on making and breaking contact When the contact was made between clean platina the spark was also very small but regular both ways The true electric spark is in fact very small and when surfaces of mercury are used it is the combustion of the metal which produces the greater part of the light The circumstances connected with the burning of the mercury are most favourable on breaking contact for the act of separation exposes clean surfaces of metal whereas on making contact a thin film of oxide or soiling matter often interferes Hence the origin of the general opinion that it is only when the contact is broken that the spark passes

959 With reference to the other set of cases namely those of local action (947) in which chemical affinity being exerted causes no trans- [illegible]

electric current they can produce become apparent although the same final state of things [illegible] had passed It [illegible]

doubtful knowledge (876) which we ought rather to strive to diminish than to increase for the very extensive contradictions of this knowledge

[1] When nitro-sulphuric acid is used the spark is more powerful but local chemical action can then commence and proceed without requiring metallic contact

[2] It has been universally supposed that no spark is [illegible]

[3] See in relation to precautions respecting a spark, 1074 —*Dec* 1838.

by itself shows that but a small portion of it can ultimately prove true [1]

960 Of the two modes of action in which chemical affinity is exerted, it is important to remark that that which produces the electric current *is as definite as that which causes ordinary* chemical combination, so that in examining the *production* or *evolution* of electricity in cases of combination or decomposition, it will be necessary, not merely to observe certain effects dependent upon a current of electricity, but also their *quantity* and though it may often happen *that the forces* concerned in any particular case of chemical action may be partly exerted in one mode and partly in the other, it is only those which are efficient in producing the current that have any relation to voltaic action Thus, in the combination of oxygen and hydrogen to produce water, electric powers to a most enormous amount are for the time active (861, 873), but any mode of examining the flame which they form during energetic combination, which has as yet been devised, has given but the feeblest traces These therefore may not, cannot, be taken as evidences of the nature of the action, but are merely incidental results, incomparably small in relation to the forces concerned, and supplying no information of the way in which the particles are active on each other, or in which their forces are finally arranged

961 That such cases of chemical action produce no *current of electricity*, is perfectly consistent with what we know of the voltaic apparatus in which it is essential that one of the combining elements shall form part of, or be in direct relation with, an electrolytic conductor (921, 923) That such cases produce no *free electricity of tension*, and that when they are converted into cases of voltaic action they produce a current in which the opposite forces are so equal as to neutralize each other, prove the equality of the forces in the opposed acting particles of matter, and therefore the equality of electric power in those quantities of matter which are called *electro-chemical equivalents* (824) Hence another proof of the definite nature of electro-chemical action (783, &c), and that chemical affinity and electricity are forms of the same power (917, &c.)

962 The direct reference of the [illegible] duced by the volt[illegible] mental d[illegible] active at [illegible] [illegible]tion (891, 917), gives a ve[illegible] simple and natural view of the cause why the bodies (or *ions*) evolved pass in certain directions, for it is only when they pass in those directions that their forces can consist with and compensate (in direction at least) the superior forces which are dominant at the place *where the action of the whole is determined* If, for instance, in a voltaic circuit, the activity of which is determined by the attraction of zinc for the oxygen of water, the zinc move from right to left, then any other *cation* included in the circuit, being part of an electrolyte, or forming part of it at the moment, will also move from right to left and as the oxygen of the water, by its natural affinity for the zinc, moves from left to right, so any other body of the same class with it (i e , any other *anion*), under its government for the time, will move from left to right.

963 This I may illustrate by reference to Pl. VII, *Fig 11*, the double circle of which may represent a complete voltaic circuit, the direction of its forces being determined by supposing for a moment the zinc *b* and the platina *c* as representing plates of those metals acting upon water, *d*, *e*, and other substances but having their energy exalted so as to effect several decompositions by the use of a battery at *a* (989) This supposition may be allowed, because the action in the battery will only consist of repetitions of what would take place between *b* and *c*, if they really constituted but a single pair The zinc *b*, and the oxygen *d*, by their mutual affinity, tend to unite, but as the oxygen is already in association with the hydrogen *e*, and has its inherent chemical or electric powers neutralized for the time by those of the latter the hydrogen *e* must leave the oxygen *d*, and advance in the direction of the arrow head, or else the zinc *b* cannot move in the same direction to unite to the oxygen *d*, nor the oxygen *d* move in the contrary *direction to unite to* the zinc *b*, the relation of the *similar* forces of *b* and *c*, in contrary directions, to the *opposite* forces of *d* being the preventive As the hydrogen *e* advances, it, on coming against the platina *c*, *f*, which forms a part of the circuit, communicates its electric or chemical forces through it to the *next electrolyte in the circuit*, fused chloride of lead, *g*, *h*, where the chlorine must move in conformity with the direction of the oxygen at *d*, for it has to compensate the forces disturbed in its part of the circuit by the superior influence of those between the oxygen and zinc at *d* *b*, aided as they are by those of the *battery a, and for a similar reason* the lead must move in the direction pointed out by the

[1] Refer to 1738, etc. Series XIV.—*Dec* 1838

and if another electrolyte, as the iodide of tin, occur at *l*, *m*, then the iodine *l*, being an *anion*, must move in conformity with the exciting *anion*, namely, the oxygen *d*, and the *cation* tin *m* move in correspondence with the other *cations* *b*, *e*, and *h*, that the chemical forces may be in equilibrium as to their direction and quantity throughout the circuit Should it so happen that the anions in their circulation can combine with the metals at the *anodes* of the respective electrolytes, as would be the case at the platina *f* and the copper *k*, then those bodies becoming parts of electrolytes, under the influence of the current, immediately travel, but considering their relation to the zinc *b*, it is evidently impossible that they can travel in any other direction than what will accord with its course, and therefore can never tend to pass otherwise than *from* the anode and *to* the cathode

964 In such a circle as that delineated, therefore all the known *anions* may be grouped within, and all the *cations* without If any number of them enter as *ions* into the constitution

lead, copper and tin, at *e*, *h*, *k*, and *m*

965 If the present paper be accepted as a correct expression of facts, it will still only prove a confirmation of certain general views put forth by Sir Humphry Davy in his Bakerian Lecture for 1806,[1] and revised and re-stated by him in another Bakerian Lecture, on electrical and chemical changes, for the year 1826[2] His general statement is that *chemical and*

the phenomena exhibited by different voltaic combinations[3] This statement I believe to be true, but in admitting and supporting it, I must guard myself from being supposed to assent to all that is associated with it in the two papers referred to, or as admitting the experiments which are there quoted as decided proofs of the

reasons for the judgment in both cases But then I should be equally bound to review, for the same purpose, all that has been written both for and against the necessity of metallic contact—for and against the origin of voltaic electricity in chemical action—a duty which I may not undertake in the present paper[4]

¶ ii *On the Intensity Necessary for Electrolyzation*

electric current as a metal does, after they cease to conduct as electrolytes, or would act

ments, to determine whether a current could really pass through and yet not decompose an electrolyte (910)

[1] *Philosophical Transactions* 1807
[2] *Ibid*, 1826 p 383

[3] *Ibid* 1826 p 389
[4] I at one time intended to introduce here in the

plate *z* was amalgamated zinc, in connexion, by a platina wire *a*, with the platina plate *e*, *b* was a platina wire connecting the two platina plates P P′, *c* was a platina wire connected with the platina plate P″. On the plate *e* was placed a piece of paper moistened in solution of iodide of potassium the wire *c* was so curved that its end could be made to rest at pleasure on this paper, and show, by the evolution of iodine there, whether a current was passing, or, being placed in the dotted position, it formed a direct communication with the platina plate *e*, and the electricity could pass without causing decomposition The object was to produce a current by the action of the acid on the amalgamated zinc in the first vessel A to pass it through the acid in the second vessel B *by platina electrodes, that its power of decomposing* water might, if existing, be observed, and to verify the existence of the current at pleasure, by decomposition at *e*, without involving the continual obstruction to the current which would arise from making the decomposition there constant The experiment, being arranged, was examined and the existence of a current ascertained by the decomposition at *e*, the whole was then left with the end of the wire *c* resting on the plate *e*, so as to form a constant metallic communication there

969 After several hours, the end of the wire *c* was replaced on the test paper at *e* decomposition occurred, and *the proof* of a passing current was therefore complete The current was very feeble compared to what it had been at the beginning of the experiment, because of a peculiar state acquired by the metal surfaces in the second vessel, which caused them to oppose the passing current by a force which

not the slightest appearance of a bubble upon either of the plates in that vessel occurred From the results of the experiment, I conclude that a current *had* passed, but of so low an intensity as to fall beneath that degree at which the elements of water, unaided by any secondary force resulting from the capability of combination with the matter of the electrodes or of the liquid surrounding them, separated from each other

water, and finally to have escaped at the surface, or to have reunited into water That the hydrogen can be so dissolved was shown in the first vessel, for after several days minute bubbles of gas gradually appeared upon a glass rod,

this way notwithstanding the amalgamation

because of its action as a nucleus on the solution supposed to be formed, but none appeared even after twelve days

973 When a few drops only of nitric acid were added to the vessel A (Pl. VII, *Fig 12*),

current (which by trial at *e* was found at the

fifteen minutes during that time no bubbles appeared upon them, but on restoring the com-

by dilute sulphuric acid alone has *not* sufficient intensity

974 On using a strong solution of caustic potassa in the vessel A, to excite the current it

be passing still not the slightest appearance of gas appeared on the plates P P, nor any other signs of the water having suffered decomposition

975 Sulphate of soda in solution was then experimented with, for the purpose of ascertaining with respect to it whether a certain electrolytic intensity was also required for its decomposition in this state, in analogy with the result established with regard to water (974) The apparatus was arranged as in Pl VII *Fig 13*, P and Z are the platina and zinc

ready command, as far as arrangement was

composition was to be effected were placed upon it, the wires from P and Z resting upon these pieces of paper, or upon the plate *c* according as the current with or without decomposition of the solutions was required

976. *On placing solution of iodide of potassium in paper at one of the decomposing localities* and solution of sulphate of soda at the

the sulphate of soda alone was subject to ac-

bibulous litmus and turmeric paper At the end of that time it was ascertained by the decomposition of iodide of potassium at the second place of action that the current was passing and had passed for the twelve hours, and yet no trace of acid or alkali from the sulphate of soda appeared

977 From these experiments it may, I think,

solution

978 *I then experimented on bodies rendered decomposable by fusion*, and first on *chloride*

was then made to traverse a little chloride of lead fused upon glass at *a* a paper moistened in solution of iodide of potassium at *b*, and a

iodide of potassium at *b*, and when metallic

of the fused chloride at *a* and

appearance of a decomposition having been effected there

980 A further proof of decomposition was obtained

wires in the fused chloride at *a* were brought very near together (metallic contact having been established at *b*), and left so, the deflection at the galvanometer indicated the passage of a current, feeble in its force, but constant After a minute or two, however, the needle would suddenly be violently affected, and indicate a current as strong as if metallic contact had taken place at *a* This I actually found to be the case, for the silver reduced by the action of the current crystallized in long delicate spiculæ, and these at last completed the metallic communication, and at the *same time* that they transmitted a more powerful current than the fused chloride, they proved that electro-chemical decomposition of that chloride had been going on Hence it appears, that the current excited by dilute sulphuric acid between zinc and platina, has an intensity above that required to electrolyze the fused chloride of silver when placed between platina electrodes, although it has not intensity enough to decompose chloride of lead under the same circumstances

981 A drop of water placed at *a* instead of the fused chlorides, showed as in the former case (970), that it could conduct a current unable to decompose it for decomposition of the solution of iodide at *b* occurred after some time But its conducting power was much below that of the fused chloride of lead (978)

982 Fused nitre at *a* conducted much better than water I was unable to decide with certainty whether it was electrolyzed, but I incline to think not, for there was no discoloration against the platina at the *cathode* If sulpho-nitric acid had been used in the exciting vessel, both the nitre and the chloride of lead would have suffered decomposition like the water (906)

983 The results thus obtained of conduction without decomposition, and the necessity of a certain electrolytic intensity for the separation of the ions of different electrolytes, are immediately connected with the experiments and results given in § 10 of the Fourth Series of these *Researches* (418, 423, 444, 449) But it will require a more exact knowledge of the nature of intensity, both as regards the first origin of the electric current, and also the manner in which it may be reduced, or lowered by the intervention of longer or shorter portions of bad conductors, whether decomposable or not, before their relation can be minutely and fully understood

984 In the case of water, the experiments I have as yet made, appear to show that, when the electric current is reduced in intensity below the point required for decomposition, then the degree of conduction is the same whether sulphuric acid, or any other of the many bodies which can affect its *transferring* power as an electrolyte, are present or not. Or, in other words, that the necessary electrolytic intensity for water is the same whether it be pure, or rendered a better conductor by the addition of these substances, and that for currents of less intensity than this, the water, whether pure or acidulated, has equal conducting power An apparatus (Pl VII, *Fig 12*), was arranged with dilute sulphuric acid in the vessel A, and pure distilled water in the vessel B By the decomposition at *e*, it appeared as if water was a *better* conductor than dilute sulphuric acid for a current of such low intensity as to cause no decomposition I am inclined, however, to attribute this apparent superiority of water to variations in that peculiar condition of the platina electrodes which is referred to farther on in this Series (1040), and which is assumed as far as I can judge, to a greater degree in dilute sulphuric acid than in pure water The power therefore, of acids, alkalies, salts, and other bodies in solution, to increase conducting power, appears to hold good only in those cases where the electrolyte subject to the current suffers decomposition, and loses all influence when the current transmitted has too low an intensity to affect chemical change It is probable that the ordinary conducting power of an electrolyte in the solid state (419) is the same as that which it possesses in the fluid state for currents, the tension of which is beneath the due electrolytic intensity

985 Currents of electricity, produced by less than eight or ten series of voltaic elements, can be reduced to that intensity at which water can conduct them without suffering decomposition, by causing them to pass through three or four vessels in which water shall be successively interposed between platina surfaces The principles of interference upon which this effect depends, will be described hereafter (1009, 1018), but the effect may be useful in obtaining currents of standard intensity, and is probably applicable to batteries of any number of pairs of plates

986 As there appears every reason to expect that all electrolytes will be found subject to the law which requires an electric current of a certain intensity for their decomposition, but that they will differ from each other in the degree of intensity required, it will be desirable

hereafter to arrange them in a table, in the order of their electrolytic intensities Investigations on this point must, however, be very *much extended* and *include many more bodies* than have been here mentioned before such a table can be constructed It will be especially needful in such experiments, to describe the nature of the electrodes used, or, if possible, to select such as, like platina or plumbago in certain cases, shall have no power of assisting the separation of the *ions* to be evolved (913)

987 [illegible]

[illegible] it is accompanied by decomposition, the first [illegible]

[illegible] may hereafter be extended to the metals for their power of conducting without decomposition may, perhaps justly, be ascribed to their requiring a very high electrolytic intensity for their decomposition

987½ The establishment of the principle [illegible]

[illegible] (913), that a very weak current [illegible] to raise the sum of actions sufficiently high, and cause chemical changes to occur

938 In concluding this division *on the intensity necessary for electrolyzation*, I cannot resist pointing out the following remarkable conclusion in relation to intensity generally It would appear that when a voltaic current is produced, having a certain intensity, dependent upon the strength of the chemical affinities by which [illegible]

[illegible] ciding whether the electrolyte shall give way or not If that conclusion be confirmed, then we may arrange circumstances so that the *same quantity* of electricity may pass in the *same time*, in at the *same surface*, into the *same decomposing body in the same state*, and yet, differing in intensity, will *decompose in one case and in the other not* for taking a source of too low an intensity to decompose, and ascertaining the quantity passed in a given time it is easy to take another source having a sufficient intensity, and reducing the quantity of electricity from it by the intervention of bad conductors to the same proportion as the former current, and then all the conditions will be fulfilled which are required to produce the result described

¶ iii *On Associated Voltaic Circles, or the Voltaic Battery*

[illegible] affinities, in place of being opposed to each other as in Pl VII, *Figs 1, 4* (880, 891), are made to act in conformity, then, instead of either interfering with the other, it will rather assist it. This is simply the case of two voltaic pairs of metals arranged so as to form one circuit In such arrangements the activity of the whole is known to be increased, and when ten, or a hundred, or any larger number of such al [illegible]

[illegible] five pounds of metal [illegible]

a definite portion of water in that cell, [illegible]

pass from the zinc to the platina across the acid in the second cell, without the decomposition of the same quantity of water there, and the oxidation of the same quantity of zinc by it (924, 949) The same result recurs in every other cell the electro-chemical equivalent of water must be decomposed in each, before the current can pass through it, for the quantity of electricity passed and the quantity of electrolyte decomposed, *must* be the equivalents of each other The action in each cell, therefore is not to increase the quantity set in motion in any one cell but to aid in urging forward that quantity, the passing of which is consistent with the oxidation of its own zinc and in this way it exalts that peculiar property of the current which we endeavour to express by the term *intensity*, without increasing the *quantity* beyond that which is proportionate to the quantity of zinc oxidized in any single cell of the series

991 *To prove this I arranged ten pairs of amalgamated zinc and platina plates with dilute sulphuric acid in the form of a battery On completing the circuit* all the pairs acted and evolved gas at the *surfaces of the platina* This was collected and found to be alike in quantity for each plate and the quantity of hydrogen evolved at any one platina plate was in the same proportion to the quantity of metal dissolved from any one zinc plate, as was given in the experiment with a single pair (864, &c) It was therefore certain that, just as much electricity and no more had passed through the series of ten pair of plates as had passed through or would have been put into motion by, any single pair, notwithstanding that ten times the quantity of zinc had been consumed

992 This truth has been proved also long ago in another way, by the action of the evolved current on a magnetic needle the deflecting power of one pair of plates in a battery being equal to the deflecting power of the whole, provided the wires used be sufficiently large to carry the current of the single pair freely but the *cause* of this equality of action could not be understood whilst the definite action and evolution of electricity (783, 869) remained unknown

993 The *superior decomposing power of a* battery over a *single pair of plates is rendered* evident in two ways *Electrolytes held together by an affinity so strong* as to resist the action of the *current from a single pair*, yield up *their elements to the current excited by many* pairs, and that body which is decomposed by the action of one or of few pairs of metals, &c., is resolved into its ions the more readily as it is acted upon by electricity urged forward by many alternations

994 Both these effects are, I think, easily understood Whatever *intensity* may be (and that must of course depend upon the nature of electricity, whether it consist of a fluid or fluids, or of vibrations of an ether, or any other kind or condition of matter), there seems to be no difficulty in comprehending that the *degree* of intensity at which a current of electricity is evolved by a first voltaic element shall be increased when that current is subjected to the action of a second voltaic element, acting in conformity and possessing equal powers with the first and as the decompositions are merely opposed actions, but exactly of the same *kind* as those which generate the current (917) *it seems to be a natural consequence that the affinity which can resist the force of a single decomposing action may be unable to oppose the energies of many decomposing actions, operating conjointly, as in the voltaic battery*

995 *That a body which can give way to a current of feeble intensity* should give way more freely to one of stronger force, and yet involve no contradiction to the law of definite electrolytic action, is perfectly consistent All the facts and also the theory I have ventured to put forth tend to show that the act of decomposition opposes a certain force to the passage of the electric current and, that this obstruction should be overcome more or less readily, in proportion to the greater or less intensity of the decomposing current, is in perfect consistency with all our notions of the electric agent.

996 I have elsewhere (947) distinguished the chemical action of zinc and dilute sulphuric acid into two portions, that which, *acting* effectually on the zinc, evolves *hydrogen* at once upon its surface, and that which *producing* an arrangement of the *chemical forces* throughout the electrolyte present (in this case water), *tends to take oxygen from it but cannot do so unless the electric current consequent thereon can have free passage and the hydrogen be delivered elsewhere than against the zinc* The electric current depends altogether upon the second of these but when the current can pass, by favouring the electrolytic action it tends to diminish the former and increase the latter portion

997 It is evident therefore, that when ordinary zinc is used in a voltaic arrangement, there is an enormous waste of that power which

it is the object to throw into the form of an electric current, a consequence which is put in its strongest point of view when it is considered that three ounces and a half of zinc, properly oxidized, can circulate enough electricity to decompose nearly one ounce of water, and cause the evolution of about 2400 cubic inches of hydrogen gas This loss of power not only takes place during the time the electrodes of the battery are in communication, being then proportionate to the quantity of hydrogen evolved against the surface of any one of the zinc plates, but includes also *all* the chemical action which goes on when the extremities of the pile are not in communication

998 This loss is far greater with ordinary zinc than with the pure metal, as M De la Rive has shown [1] The cause is that when ordinary zinc is acted upon by dilute sulphuric acid, portions of copper, lead, cadmium, or other metals which it may contain, are set free upon its surface, and these, being in contact with the zinc, form small but very active vol-

surface of these incidental metals In the same proportion as they serve to discharge or convey the electricity back to the zinc, do they diminish its power of producing an electric cur

paratus

amalgamated zinc plates of Mr Sturgeon (863), who has himself suggested and objected to their application in galvanic batteries, for he says,

teries would become an important improvement for the metal would last much longer, and remain bright for a considerable time, even for several successive hours essential considerations in the employment of this apparatus [2 3]

[1] *Quarterly Journal of Science* 1831 p 388 or *Bibliothèque* ... 1830 p 391

1000 Zinc so prepared, even though impure, does not sensibly decompose the water of dilute

erful and abundant electric current is produced It is probable that the mercury acts by bringing the surface in consequence of its fluidity, into one uniform condition, and preventing those differences in character between one spot and another which are necessary for the formation of the minute voltaic circuits referred to (998) If any difference does exist at the first

least mercury is first acted on, and by solution of the zinc, is soon placed in the same condition as the other parts, and the whole plate rendered superficially uniform One part cannot, therefore, act as a discharger to another, and hence *all* the chemical power upon the water at its surface is in that equable condition (949), which, though it tends to produce an

lent and important consequences follow upon this state of the metal The first is, that the

so prepared, and charged with dilute sulphuric acid is active only whilst the electrodes are connected, and ceases to act or be acted upon by the acid the instant the communication is broken

tasses The liquid used was ... acid of sp gr 1 25 No action took place upon

the battery, and no waste of the powers of the metal was incurred

1002 In consequence of this circumstance, the acid in the cells remained active for a very much longer time than usual In fact, time did not tend to lower it in any sensible degree for whilst the metal was preserved to be acted upon at the proper moment the acid also was preserved almost at its first strength Hence a constancy of action far beyond what can be obtained by the use of common zinc

1003 Another excellent consequence was the renewal, during the interval of rest, between two experiments of the first and most efficient state When an amalgamated zinc and a platina plate, immersed in dilute sulphuric acid, are first connected, the current is very powerful, but instantly sinks very much in force, and in some cases actually falls to only an eighth or a tenth of that first produced (1036) This is due to the acid which is in contact with the zinc becoming neutralized by the oxide formed, the continued quick oxidation of the metal being thus prevented With ordinary zinc, the evolution of gas at its surface tends to mingle all the liquid together, and thus bring fresh acid against the metal, by which the oxide formed there can be removed With the amalgamated zinc battery, at every cessation of the current the saline solution against the zinc is gradually diffused amongst the rest of the liquid and upon the renewal of contact at the electrodes, the zinc plates are found most favourably circumstanced for the production of a ready and powerful current

1004 It might at first be imagined that amalgamated zinc would be much inferior in force to common zinc, because of the lowering of its energy, which the mercury might be supposed to occasion over the whole of its surface, but this is not the case When the electric currents of two pairs of platina and zinc plates were opposed, the difference being that one of the zincs was amalgamated and the other not, the current from the amalgamated zinc was most powerful, although no gas was evolved against it, and much was evolved at the surface of the unamalgamated metal Again, as Davy has shown,[1] if amalgamated and unamalgamated zinc be put in contact, and dipped into dilute sulphuric acid, or other exciting fluids, the former is positive to the latter, i e , the current passes from the amalgamated zinc, through the fluid, to the unprepared zinc This he accounts for by supposing that "there is not any inherent and specific property in each metal which gives it the electrical character, but that it depends upon its peculiar state—on that form of aggregation which fits it for chemical change"

1005 The superiority of the amalgamated zinc is not, however, due to any such cause but is a very simple consequence of the state of the fluid in contact with it, for as the unprepared zinc acts directly and alone upon the fluid, whilst that which is amalgamated does not, the former (by the oxide it produces) quickly neutralizes the acid in contact with its surface so that the progress of oxidation is retarded, whilst at the surface of the amalgamated zinc, any oxide formed is instantly removed by the free acid present, and the clean metallic surface is always ready to act with full energy upon the water Hence its superiority (1037)

1006 The progress of improvement in the voltaic battery and its applications, is evidently in the contrary direction at present to what it was a few years ago for in place of increasing the number of plates, the strength of acid, and the extent altogether of the instrument the change is rather towards its first state of simplicity, but with a far more intimate knowledge and application of the principles which govern its force and action Effects of decomposition can now be obtained with ten pairs of plates (417), which required five hundred or a thousand pairs for their production in the first instance The capability of decomposing fused chlorides, iodides, and other compounds according to the law before established (380, &c) and the opportunity of collecting certain of the products, without any loss, by the use of apparatus of the nature of those already described (789, 814, &c), render it probable that the voltaic battery may become a useful and even economical manufacturing instrument for theory evidently indicates that an equivalent of a rare substance may be obtained at the expense of three or four equivalents of a very common body, namely, zinc and practice seems thus far to justify the expectation In this point of view I think it very likely that plates of platina or silver may be used instead of plates of copper with advantage, and that then the evil arising occasionally from solution of the copper, and its precipitation on the zinc (by which the electromotive power of the zinc is so much injured) will be avoided (1047)

¶ iv *On the Resistance of an Electrolyte to Electrolytic Action, and on Interpositions*

1007. I have already illustrated, in the am-

[1] *Philosophical Transactions* 1826 p 405.

plest possible form of experiment (891, 910), the resistance established at the place of de-

the action and phenomena of the voltaic bat-

the resistance of the chemical affinities to be

correct account of the whole could be given

1008 As it will be convenient to describe the experiments in a form different to that in which they were made, both forms shall first be explained Plates of platina, copper, zinc, and other metals, about three quarters of an inch wide and three inches long, were associated together in pairs by means of platina wires to

small glass rods were put into the cups, be-

in a decomposing apparatus (899, 903, &c), or both Now if Pl VIII, Fig 3, be examined and compared with Fig 4, the latter may be admitted as representing the former in its simplest condition; for the cups I, II, and III of the former, with their contents, are represented by the cells I, II, and III of the latter, and the metal plates Z and P of the former by the similar plates represented Z and P in the latter The only difference, in fact, between the apparatus, Fig 3, and the trough represented Fig 4, is that twice the quantity of surface of contact between the metal and acid is allowed in the first to what would occur in the second

1009 When the extreme plates of the arrangement just described (Pl VIII, Fig 3), are connected metallically through the galvanometer g, then the whole represents a battery consisting of two pairs of zinc and platina plates urging a current forward, which has, however, to decompose water unassisted by any direct chemical affinity before it can be transmitted across the cell III, and therefore before it can circulate This decomposition of water, which is opposed to the passage of the current, may, as a matter of convenience, be considered as taking place either against the surfaces of the

cells II and III, Fig 4, from each other It is evident that if that plate were away, the battery would consist of two pairs of plates and two cells, arranged in the most favourable position for the production of a current The plat-

of any obstruction arising from the decomposition of water by the electrolytic action of the current and I have usually called it the interposed plate

1010 In order to simplify the conditions, dilute sulphuric acid was first used in all the cells, and platina for the interposed plates for then the initial intensity of the current which tends to be formed is constant, being due to the power which zinc has of decomposing water and the opposing force of decomposition is also constant, the elements of the water being unassisted in their separation at the interposed plates by any affinity or secondary action at the electrodes (744), arising either from the nature of the plate itself or the surrounding fluid

1011 When only one voltaic pair of zinc and platina plates was used, the current of electricity was entirely stopped to all practical

a second separation of the elements of water Such an effect would require that the force of attraction between zinc and oxygen should un-

PLATE VIII


Fig 1

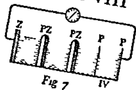


Fig 7


Fig 2

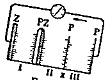


Fig 4

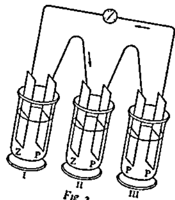


Fig 3

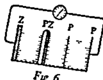


Fig 6

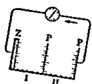


Fig 5

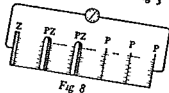


Fig 8

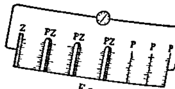


Fig 9

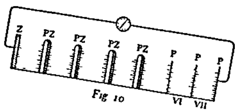


Fig 10

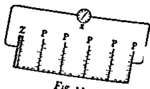


Fig 11

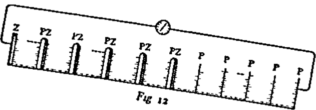


Fig 12

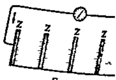


Fig 15

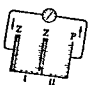


Fig 13

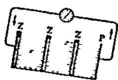
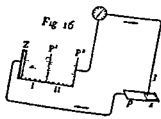


Fig 14

Fig 16


1012 When two pairs of zinc and platina exciting plates were used, the current was also practically stopped by *one* interposed platina plate (Pl VIII, *Fig 6*) There was a very feeble effect of a current at first, but it ceased almost immediately It will be referred to, with many other similar effects, hereafter (1017)

1013 Three pairs of zinc and platina plates

tinued deflection of the galvanometer, and the production of bubbles of oxygen and hydrogen at the electrodes in cell IV Hence the accumulated surplus force of three plates of zinc,

1014 The three pairs of zinc and platina plates were now opposed by two intervening platina plates (Pl VIII, *Fig 8*) In this case the current was stopped

1015 Four pairs of zinc and platina plates were also neutralized by two interposed platina plates, *Fig 9*

1016 Five pairs of zinc and platina, with two interposed platina plates, *Fig 10*, gave a feeble current, there was permanent deflection at the galvanometer, and decomposition in the cells VI and VII But the current was very feeble, very much less than when all the intermediate plates were removed and the two extreme ones only retained for when they were placed six inches asunder in one cell, they gave a powerful current Hence five exciting pairs, with two interposed obstructing plates, do not give a current at all comparable to that of a single *unobstructed pair*

1017 I have already said that a *very feeble current* passed when the series included one interposed platina and two pairs of zinc and

decomposition of water (970, 984), for water can conduct electricity of such low intensity by the same kind of power which it possesses in common with metals and charcoal, though it cannot conduct electricity of higher intensity

increased difficulty of conduction

1018 In order to obtain an idea of the additional interfering power of each added platina plate, six voltaic pairs and four intervening platinas were arranged as in Pl VIII *Fig 12*, a very feeble current then passed (985 1017) When one of the platinas was removed so that three intervened a current somewhat stronger passed With two intervening platinas a still stronger current passed, and with only one intervening platina a very fair current was obtained. But the effect of the successive plates, taken in the order of their interposition, was

mated and unamalgamated zinc were used, but the results generally were the same

1020 The effects of retardation just described were altered altogether when changes were

tarding cells, then the transmission of the current was very much facilitated For instance, in the experiment with one pair of exciting plates and one intervening plate (1011) (Pl VIII, *Fig 5*), when a few drops of nitric acid were added to the contents of cell II, then the

terposed plates were used

1021 This seems to be a consequence of the diminution of the difficulty of decomposing water when its hydrogen, instead of being absolutely expelled, as in the former cases, is transferred to the oxygen of the nitric acid, producing a secondary result at the *cathode* (752), for in accordance with the chemical views of the electric current and its action already

advanced (913), the water, instead of opposing a resistance to decomposition equal to the full amount of the force of mutual attraction between its oxygen and hydrogen has that force counteracted in part, and therefore diminished by *the attraction of the hydrogen at the cathode* for the oxygen of the nitric acid which surrounds it, and with which it ultimately combines instead of being evolved in its free state

1022 When a little nitric acid was put into the exciting cells, then again the circumstances favouring the transmission of the current were strengthened, for the *intensity* of the current itself was increased by the addition (906) When therefore a little nitric acid was added to both the *exciting* and the *retarding* cells, the current of electricity passed with very considerable freedom

1023 When dilute muriatic acid was used, it produced and transmitted a current more easily than pure dilute sulphuric acid, but not so readily as dilute nitric acid As muriatic acid appears to be decomposed more freely than water (765), and as the affinity of zinc for chlorine is very powerful, it might be expected to produce a current more intense than that from the use of dilute sulphuric acid, and also to transmit it more freely by undergoing decomposition at a lower intensity (912)

1024 In relation to the effect of these interpositions, it is necessary to state that they do not appear to be at all dependent upon the size of the electrodes, or their distance from each other in the acid, except that when a current *can pass, changes in these facilitate or retard* its passage For on repeating the experiment with one intervening and one pair of exciting plates (1011), Pl VIII, *Fig 5*, and in place of the interposed plate P using sometimes a mere wire, and sometimes very large plates (1008), and also changing the terminal exciting plates Z and P, so that they were sometimes wires only and at others of great size, still the results were the same as those already obtained

1025 In illustration of the effect of distance, an experiment like that described with two exciting pairs and one intervening plate (1012), Pl VIII, *Fig 6*, was arranged so that the distance between the plates in the third cell could be increased to six or eight inches, or diminished to the thickness of a piece of intervening bibulous paper Still the result was the same in both cases, the effect not being sensibly greater, when the plates were merely separated by the paper, than when a great way apart, so that the principal opposition to the current in this case does not depend upon the *quantity* of intervening electrolytic conductor, but on the *relation of its elements to the intensity of the current*, or to the chemical nature of the electrodes and the surrounding fluids

1026 When the acid was sulphuric acid, *increasing its strength* in any of the cells caused no change in the effects it did not produce a more intense current in the exciting cells (908), or cause the current produced to traverse the decomposing cells more freely But if to very weak sulphuric acid a few drops of nitric acid were added, then either one or other of those effects could be produced and, as might be expected in a case like this, where the exciting or conducting action bore a *direct* reference to the acid itself, increasing the strength of this (the nitric acid) also increased its powers.

1027 The *nature of the interposed plate* was now varied to show its relation to the phenomena either of excitation or retardation, and amalgamated zinc was first substituted for platina On employing one voltaic pair and one interposed zinc plate (Pl VIII, *Fig 13*), there was as powerful a current, apparently, as if the interposed zinc plate was away Hydrogen was evolved against P in cell II, and against the side of the second zinc in cell I, but no gas appeared against the side of the zinc in cell II, nor against the zinc in cell I

1028 On interposing two amalgamated zinc plates (Pl VIII, *Fig 14*), instead of one there was still a powerful current, but interference had taken place On using three intermediate zinc plates, *Fig 15*, there was still further retardation, though a good current of electricity passed

1029 Considering the retardation as due to the inaction of the amalgamated zinc upon the dilute acid, in consequence of the slight though general effect of diminished chemical power produced by the mercury on the surface, and viewing this inaction as the circumstance which rendered it necessary that each plate should have its tendency to decompose water assisted slightly by the electric current, it was expected that plates of the metal in the unamalgamated state would probably not require such assistance, and would offer no sensible impediment to the passing of the current This expectation was fully realized in the use of two and three interposed unamalgamated plates *The electric current passed through them as freely as if* there had been no such plates in the way They offered no obstacle, because *they could decompose* water without the current, and the latter

had only to give direction to a part of the forces, which would have been active whether it had passed or not

1030 Interposed plates of copper were then employed These seemed at first to occasion no obstruction, but after a few minutes the current

reverse current, for when one or more of the plates were turned round, which could easily be effected with the *couronne des tasses* form of experiment (Pl VIII, *Fig 3*), then the current was powerfully renewed for a few moments, and then again ceased Plates of platina and copper, arranged as a voltaic pile with dilute sulphuric acid, could not form a voltaic trough

ity, or are *altogether deficient in attraction*, show generally, though beautifully, the chemical relations and source of the current, and also the balanced state of the affinities at the places of excitation and decomposition In this way they add to the mass of evidence in favour of the identity of the two, for they demon-

chemical and electrical action are merely two exhibitions of one single agent or power (916, &c)

electricity is of sufficiently low intensity, it may not be asserted as absolutely true in all cases that whenever electricity passes through an electrolyte it produces a definite effect of

for electrolyzation, I have found no sensible departure as yet from the law of *definite electrolytic action* developed in the preceding series of these *Researches* (783 &c)

1033 I cannot dismiss this division of the present paper without making a reference to the important experiments of M Aug De la Rive on the effects of interposed plates [1] As I have had occasion to consider such plates merely as giving rise to new decompositions, and in that way only causing obstruction to the pas-

Ritter,[4] which are connected with it

¶ v *General Remarks on the Active Voltaic Battery*

1034 When the ordinary voltaic battery is brought into action, its very activity produces *certain effects, which react upon it*, and cause serious deterioration of its power These render it an exceedingly inconstant instrument as to the *quantity* of effect which it is capable of pro-

terposed platina plates [5]

1036 I have already referred to this consequence (1003), as capable, in some cases of

interference was very great In an experiment in which one voltaic pair and one interposed platina plate were used with dilute sulphuric acid in the cells (Pl VIII, *Fig 16*), the wires of

[1] *Annales de Chimie* Vol XXVIII p 190 and *Mémoires de Genève*
[2] *Philosophical Transactions* 1826 p 413.
[3] *Annales de Chimie* Vol XXXIII pp 117 119 &c.
[4] *Journal de Physique* Vol LVII pp 349 350
[5] *Philosophical Transactions* 1826 p 413.

communication were so arranged, that the end of that marked 3 could be placed at pleasure upon paper moistened in the solution of iodide of potassium at x, or directly upon the platina plate there If, after an interval during which the circuit had not been complete, the wire 3 were placed upon the paper, there was evidence of a current, decomposition ensued, and the galvanometer was affected If the wire 3 were made to touch the metal of p, a comparatively strong sudden current was produced, affecting the galvanometer, but lasting only for a moment, the effect at the galvanometer ceased, and if the wire 3 were placed on the paper at x, no signs of decomposition occurred On raising the wire 3, and breaking the circuit altogether for a while,

tact between 3 and p, there was again a momentary current, and immediately all the effects apparently ceased

1037 This effect I was ultimately able to refer to the state of the film of fluid in contact with the zinc plate in cell i The acid of that film is instantly neutralized by the oxide formed, the oxidation of the zinc cannot, of course, go on with the same facility as before, and the chemical action being thus interrupted, the voltaic action diminishes with it The time of the rest was required for the diffusion of the liquid, and its replacement by other acid From the serious influence of this cause in experiments with single pairs of plates of different metals, in which I was at one time engaged, and the extreme care required to avoid it, I cannot help feeling a strong suspicion that it interferes more frequently and extensively than experimenters are aware of, and therefore direct their attention to it

1038 In considering the effect in delicate experiments of this source of irregularity of action in the voltaic apparatus, it must be remembered that it is only that very small por-

in it, taken out, and wiped dry it was put into a second portion of distilled water, moved about in it, and again wiped it was put into a third portion of distilled water, in which it was moved

minutes The two latter portions of water were then tested for sulphuric acid, the third gave no sensible appearance of that substance but the fourth gave indications which were not merely evident, but abundant for the circumstances under which it had been introduced

contact of the fluid formed against the plate in the voltaic circuit must be as *intimate and* as perfect as possible, it is easy to see how

must be

1039 In the ordinary voltaic pile, the influence of this effect will occur in all variety of degrees The extremities of a trough of twenty pairs of plates of Wollaston's construction were

bubbles of gas issuing from the extremity of the tube, in consequence of the decomposition of the water, noted Without moving the plates the acid between the copper and zinc was agitated by the introduction of a feather The bubbles were immediately evolved more rap-

feather must have been a very imperfect mode of restoring the acid in the cells against the plates towards its first equal condition and yet imperfect as the means were, they more than doubled the power of the battery The *first effect* of a battery which is known to be so superior to the degree of action which the battery can sustain, is almost entirely due to the favourable condition of the acid in contact with the plates

1040 A *second* cause of diminution in the force of the voltaic battery, consequent upon

[1] *Journal de Physique* LXII p

has been so well experimented upon by Marianini and also by A De la Rive If the apparatus Pl VIII *Fig 16* (1036) be left in act on for an hour or two with the wire 3 in contact with the plate *p* so as to allow a free passage for the current then though the contact be broken for ten or twelve minutes st ll upon its renewal only a feeble current will pass not at all equal in force to what might be expected Further if P^1 and P^2 be connected by a metal wire a powerful momentary current will pass from P^2 to P^1 through the acid and therefore in the reverse direction to that produced by

ng influence on the action of a p le especially f the latter cons st of but a small number of alternat ons and has to pass its current through many interpositions It varies with the solu t on in which the interposed plates are immersed with the intensity of the current the strength of the p le the t me of act on and especially with accidental discharges of the plates by inadvertent contacts or revers ons of the

ments already described (1036 &c) by mak ing contact between the plates P and P^2 before the effect dependent upon the state of the solut on in contact with the zinc plate was ob-

acqu red of producing a reversed current was very cons derable

1042 *Weak and exhausted charges* should

in a battery of fifty pairs of plates ten of the cells contain a weaker charge than the others it is as if ten decomposing plates were opposed to the transit of the current of forty pairs of generat ng plates (1031) Hence a serious loss of force and hence the reason why if the ten pairs of plates were removed the remaining forty pairs would be much more powerful than the whole fifty

1043 Five similar troughs of ten pairs of plates each were prepared four of them with a good uniform charge of acid and the fifth with the part ally neutralized acid of a used battery

in the circuit they produced with the same

plates after being thus used was connected with a volta-electrometer (711) so that by quickly shifting the wires of commun cation

sufficiently show the extremely injurious effect produced by the mixture of strong and weak charges in the same battery [1]

1045 In the same manner associations of *strong and weak* pairs of plates should be carefully avoided A pair of copper and platina

in fact became an interposed decompos ng

[1] The gradual ncrease n the action of the whole fifty pairs of plates was due to the elevation of temperature n the weakly charged trough by the passage of the current n consequence of wh ch the exciting energies of the fluid within were increased

plate, and therefore a retarding instead of an assisting pair

1046 The *reversal*, by accident or otherwise, of the plates in a battery has an exceedingly injurious effect It is not merely the counteraction of the current which the reversed plates can produce, but their effect also in retarding even as indifferent plates, and requiring decomposition to be effected upon their surface, in *accordance* with the course of the current, before the latter can pass They oppose the current, therefore in the first place, as interposed platina plates would do (1011—1018), and to this they add a force of opposition as counter voltaic plates I find that, in a series of four pairs of zinc and platina plates in dilute sulphuric acid, if one pair be reversed it very nearly neutralizes the power of the whole

1047 There are many other causes of reaction, retardation, and irregularity in the voltaic battery Amongst them is the not unusual one of precipitation of copper upon the zinc in the cells, the injurious effect of which has before been adverted to (1006) But their interest is not perhaps sufficient to justify any increase of the length of this paper, which is rather intended to be an investigation of the theory of the voltaic pile than a particular account of its practical application [1]

Note Many of the views and experiments in this series of my *Experimental Researches* will be seen at once to be corrections and extensions of the theory of electro-chemical decomposition, given in the fifth and seventh series of these *Researches* The expressions I would now alter are those which concern the independence of the evolved elements in relation to the poles or electrodes, and the reference of their evolution to powers entirely internal (524, 537, 661) The present paper fully shows my present views and I would refer to paragraphs 891 904, 910, 917, 918, 947, 963, 1007, 1031, &c as stating what they are I hope this note will be considered as sufficient in the way of correction at present for I would rather defer revising the whole theory of electro-chemical decomposition until I can obtain clearer views of the way in which the power under consideration can appear at one time as associated with particles giving them their chemical attraction, and at another as free electricity (493, 957) —M F

Royal Institution, March 31, 1834

[1] For further practical results relating to these points of the philosophy of the voltaic battery see Series X § 17 1160—1163 —*Dec* 1838.

NINTH SERIES

§ 15. *On the Influence by Induction of an Electric Current on itself —and on the Inductive Action of Electric Currents Generally*

Received December 18, 1834, Read January 29, 1835

1048 THE following investigations relate to a very remarkable inductive action of electric currents, or of the different parts of the same current (74), and indicate an immediate connexion between such inductive action and the direct transmission of electricity through conducting bodies, or even that exhibited in the form of a spark.

1049 The inquiry arose out of a fact communicated to me by Mr Jenkin, which is as follows If an ordinary wire of short length be used as the medium of communication between the two plates of an electromotor consisting of a single pair of metals, no management will enable the experimenter to obtain an electric shock from this wire, but if the wire which surrounds an electro-magnet be used, a shock is felt each time the contact with the electromotor is broken provided the ends of the wire be grasped one in each hand.

1050 Another effect is observed at the same time which has long been known to philosophers, namely, that a bright electric spark occurs at the place of disjunction.

1051 *A brief account of these results, with some of a corresponding character which I had observed in using long wires was published in the Philosophical Magazine* for 1834;[1] and I added to them some observations on their nature Further investigations led me to perceive the inaccuracy of my first notions, and ended in identifying these effects with the phenomena of induction which I had been fortunate enough to develop in the First Series of these *Experimental Researches* (1—59)[2] Notwithstanding

[1] Vol V pp 349 444

[2] *Philosophical Transactions* 1832 p 125.

this identity, the extension and the peculiarity of the views respecting electric currents which the results supply lead me to believe that they will be found worthy of the attention of the Royal Society

1052 The *electromotor* used consisted of a cylinder of zinc introduced between the two

the copper cylinder were supplied with stiff wires, surmounted by cups containing mercury, and it was at these cups that the contacts of wires, helices, or electro-magnets, used to complete the circuit, were made or broken

pasteboard tube had four copper wires, one twenty fourth of an inch in thickness, wound round it, each forming a helix in the same direction from end to end the convolutions of

feet The first and third wires were united together so as to form one consistent helix of 96 feet in length, and the second and fourth wires were similarly united to form a second helix, closely interwoven with the first, and 94 5 feet in length These helices may be distinguished by the numbers i and ii They were carefully examined by a powerful current of electricity, and a galvanometer, and found to have no communication with each other

1054 Another helix was constructed upon a similar pasteboard tube, two lengths of the same copper wire being used, each forty-six feet long These were *united into one* consistent helix of ninety two feet, which therefore was nearly equal in value to either of the former helices, but was *not in close* inductive association with them It may be distinguished

portions

1056 The principal *electro-magnet* employed consisted of a cylindrical bar of soft iron twenty-five inches long, and one inch and three-quarters in diameter, bent into a ring, so that the ends nearly touched, and surrounded by three coils of thick copper wire, the similar ends of which were fastened together, each of these terminations was soldered to a copper rod,

wires may therefore be considered as representing one wire, of thrice the thickness of the wire really used

1057 Other electro-magnets could be made at pleasure by introducing a soft iron rod into any of the helices described (1053, &c)

1058 The *galvanometer* which I had occasion to use was rough in its construction, having but one magnetic needle, and not at all delicate in its indications

1059 The effects to be considered *depend on the conductor* employed to complete the communication between the zinc and copper plates of the electromotor and I shall have to consider this conductor under four different forms as the helix of an electro-magnet (1056) as an ordinary helix (1053 &c) as a *long* extended wire, having its course such that the parts can exert little or no mutual influence, and as a *short* wire In all cases the conductor was of copper

1060 The peculiar effects are best shown by the *electromagnet* (1056) When it was used to complete the communication at the electro-

tened in salt and water, and good contact between them and the wires retained, no shock could be felt upon *making* contact at the electromotor, but a powerful one on *breaking* contact

1061 When the *helix* i or iii (1053, &c) was used as the connecting conductor, there was

lent to one helix, having wire of double thickness, I could just obtain the sensation Using the helix of thick wire (1055) the shock was distinctly obtained On placing the tongue between two plates of silver connected by wires with the parts which the hands had heretofore

touched (1064), there was a powerful shock on *breaking* contact, but none on *making* contact

1062 The power of producing these phenomena exists therefore in the simple helix, as in the electro-magnet, although by no means in the same high degree

1063 On putting a bar of soft iron into the helix, it became an electro-magnet (1057), and its power was instantly and greatly raised On putting a bar of copper into the helix, no change was produced, the action being that of the helix alone The two helices i and ii, made into one helix of *twofold length of wire, produced* a greater effect than either i or ii alone

1064 On descending from the helix to the mere *long wire*, the following effects were obtained A copper wire, 0 18 of an inch in diameter, and 132 feet in length, was laid out upon the floor of the laboratory, and used as the connecting conductor (1059) it gave no sensible spark on making contact, but produced a bright one on breaking contact, yet not so bright as that from the helix (1061) On endeavouring to obtain the electric shock at the moment contact was broken, I could not succeed so as to make it pass through the hands but by using two silver plates fastened by small wires to the extremity of the principal wire used, and introducing the tongue between those plates, I succeeded in obtaining powerful shocks upon the tongue and gums, and could easily convulse a flounder, an eel, or a frog None of these effects could be obtained directly *from* the electromotor, i e, when the tongue, frog, or fish was in a similar, and therefore comparative manner, interposed in the course of the communication between the zinc and copper plates, separated everywhere else by the acid used to excite the combination, or by air The bright spark and the shock, produced only on breaking contact, are therefore *effects of the same kind* as those produced in a higher degree by the helix, and in a still higher degree by the electro-magnet

1065 In order to compare an extended wire *with a helix, the helix i, containing ninety-six* feet, and ninety-six feet of the same-sized wire lying on the floor of the laboratory, were used alternately as conductors the former gave a much brighter spark at the moment of disjunction than the latter Again, twenty-eight feet of copper wire were made up into a helix, and being used gave a good spark on disjunction at the electromotor being then *suddenly* pulled out and again employed, it gave a much smaller spark than before, although nothing but its spiral arrangement had been changed.

1066 As the superiority of a helix over a wire *is important to the philosophy of the effect*, I took particular pains to ascertain the fact with certainty. A wire of copper sixty seven feet long was bent in the middle so as to form a double termination which could be *communicated with the electromotor*, one of the halves of this wire was made into a helix and the other remained in its extended condition When these were used alternately as the connecting wire, the helix half gave by much *the strongest spark* It even gave a stronger spark than when it and the extended wire were used conjointly as a double conductor

1067 When a *short wire* is used, *all* these effects disappear If it be only two or three inches long, a *spark can scarcely* be perceived on breaking the junction If it be ten or twelve inches long and moderately thick, a small spark may be more easily obtained As the length is increased, the spark becomes proportionately *brighter*, until from extreme length the resistance offered by the metal as a conductor begins to interfere with the principal result

1068 The effect of elongation was *well shown* thus 114 feet of copper wire, *one-eighteenth of an inch in diameter*, were extended on the floor and used as a conductor it remained *cold*, but gave a bright spark on breaking contact. Being crossed so that the two *terminations* were in contact near the extremities, it was again used as a conductor, only twelve inches now being included in the circuit the wire became very hot from the greater quantity of electricity passing *through it, and yet the* spark on breaking contact was scarcely visible The experiment was repeated with a wire one-ninth of an inch in diameter and thirty-six *feet long* with the same results

1069 *That the effects, and also* the action, in all these forms of the experiment are identical, is evident from the manner *in which the former* can be gradually raised *from that produced by* the shortest wire to that of the most powerful *electro-magnet* and this capability of examining what will happen by the most powerful apparatus, and then experimenting for the same results, or reasoning from them, *with the weaker* arrangements, is of great advantage in making out the true principles of the phenomena

1070 The action is evidently dependent upon the wire which serves as a conductor for it *varies as that wire varies in its* length or arrangement The shortest wire may be considered as exhibiting the full effect of spark or

shock which the electromotor can produce by its own direct power all the additional force which the arrangements described can excite being due to some affection of the current either permanent or momentary in the wire itself That it is a *momentary* effect produced only at the instant of breaking contact will be fully proved (1089 1100)

except what depends upon the increased ob-

electromotor and the deflection at the galva nometer was observed then a soft iron core was put into the helix and as soon as the momentary effect was over and the needle had become stationary, it was again observed and found to stand exactly at the same division as before Thus the quantity passing through the wire when the current was continued was the same either with or without the soft iron al though the peculiar effects occurring at the moment of disjunction were very d fferent in

under consideration so as to yield an explanation of those results was ascertained in the following manner The current excited by an electromotor was passed through short wires and its intensity tried by subjecting different substances to its electrolyzing power (912 966 &c) it was then passed through the wires of the powerful electro-magnet (1056) and again examined with respect to its intensity by the same means and found unchanged Again the constancy of the *quantity* passed in the above

have increased

1073 The fact is that under many varia t ons of the experiments the permanent current *loses* in force as the effects upon breaking contact become *exalted* This is abundantly evident in the comparative experiments with

eter) on to one end of the long communicating wire and also a similar length of the same platina wire on to one end of the short communi

shock from the strong current and increased

of the constant current previously passing and by which they are ultimately produced

1074 It is highly important in using the spark as an indication by its relative brightness of these effects to bear in mind certain circumstances connected with its production and appearance (958) An ordinary electric

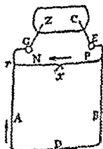
the action on, and probable combustion of, the metal, such sparks must only be compared with other sparks also taken from mercurial surfaces, and not with such as may be taken, for instance, between surfaces of platina or gold, for then the appearances are far less bright, *though the same quantity* of electricity be passed It is not at all unlikely that the commonly occurring circumstance of combustion may affect even the duration of the light, and that sparks taken between mercury, copper, or other combustible bodies, will continue for a period sensibly longer than those passing between platina or gold

1076 When the end of a short clean copper wire, attached to one plate of an electromotor, is brought down carefully upon a surface of mercury connected with the other plate, a spark, almost continuous, can be obtained *This I refer to a succession of effects of the following nature first, contact—then ignition of* the touching points—recession of the mercury from the mechanical results of the heat produced at the place of contact, and the electromagnetic condition of the parts at the moment[1] —breaking of the contact and the production of the peculiar intense effect dependent thereon—renewal of the contact by the returning surface of the undulating mercury—and then *a repetition of the same series of effects,* and *that with such rapidity as to present the ap*pearance of a continued discharge. If a long wire or an electro-magnet be used as the connecting conductor instead of a short wire, a similar appearance may be produced by tapping the vessel containing the mercury and making it vibrate, but the sparks do not usually follow each other so rapidly as to produce an apparently continuous spark, because of the time required, when the long wire or *electro-magnet* is used, both for the full development of the current (1101, 1106) and for its complete cessation

1077. Returning to the phenomena in question, the first thought that arises in the mind is that the electricity circulates with something like *momentum or inertia* in the wire, and that thus a long wire *produces effects at the instant* the current is *stopped,* which a short wire cannot produce Such an explanation is, however, at once set aside by the fact that the same length of wire produces the effects in very different degrees, according as it is simply extended, or made into a helix, or forms the circuit of an electro-magnet (1069) The experiments to be adduced (1089) will still more strikingly show that the idea of momentum cannot apply

1078 The bright spark at the electromotor, and the shock in the arms, appeared evidently to be due to *one* current in the long wire divided *into two parts by the double channel afforded through the body and through the electromotor for that the spark was evolved at the place* of disjunction with the electromotor, not by any direct action of the latter, but by a force immediately exerted in the wire of communication seemed to be without doubt (1070) It followed therefore, that by using a better conductor in place of the human body, the *whole* of this extra current might be made to pass at that place and thus be separated from *that* which the electromotor could *produce by its immediate action,* and *its direction* be *examined apart from any interference of the original* and originating current This was found to be true for on connecting the ends of the principal wire together by a cross-wire two or three feet in length, applied just where the hands had felt the shock, the whole of the extra current passed by the new channel, and then no *better* spark than one producible by a short wire was obtained on disjunction at *the electromotor*

1079 The current thus separated was *examined by galvanometers and decomposing* apparatus introduced into the course of this wire I will always speak of it as the current in the cross-wire or wires, so that no mistake, as to its place or origin may occur *In the wood-cut, Z and C represent the zinc and copper plates of* the electromotor, G and E the cups of mercury where contact is made or broken (1052) *A and* B the terminations of D, the long wire the helix or the electro-magnet, used *to complete* the circuit, *N and P are the cross wires which can either be brought into contact at x, or else have a galvanometer (1058) or an electrolysing* apparatus (312, 316) interposed there



The production of the *shock* from the current in the cross wire, whether D was a long extended wire, or a helix, or an *electro-magnet,* has been already described *(1060, 1061, 1064)*

1080 The spark of the cross-wire current could be produced at x in the following man

[1] *Quarterly Journal of Science,* Vol XII p 420.

ner D was made an electro-magnet, the metallic extremities at x were held close together, or rubbed lightly against each other, whilst contact was broken at G or E. When the communication was perfect at x, little or no spark appeared at G or E When the condition of vicinity at x was favourable for the result required, a bright spark would pass there at the moment of disjunction, *none* occurring at G and E this spark was the luminous passage of the extra current through the cross-wires When there was no contact or passage of current at x, then the spark appeared at G or E, the extra current forcing its way through the electromotor itself The same results were obtained by the use of the helix or the extended wire at D in place of the electro-magnet

1081 On introducing a fine platina wire at x, and employing the electro-magnet at D, no visible effects occurred as long as contact was continued; but on breaking contact at G or E, the fine wire was instantly ignited and fused A longer or thicker wire could be so adjusted at x as to show ignition, without fusion, every time the contact was broken at G or E

1082 It is rather difficult to obtain this effect with helices or wires, and for very simple reasons with the helices i, ii, or iii, there was such retardation of the electric current, from the length of wire used, that a full inch of platina wire one-fiftieth of an inch in diameter could be retained ignited at the cross-wires during the *continuance of contact*, by the portion of electricity passing through it Hence it was impossible to distinguish the particular effects at the moments of making or breaking contact from this constant effect On using the thick wire helix (1055), the same results ensued

1083 Proceeding upon the known fact that electric currents of great quantity but low intensity, though able to ignite thick wires, cannot produce that effect upon thin ones, I used a very fine platina wire at x, reducing its diameter until a spark appeared at G or E, when contact was broken there A quarter of an inch of such wire might be introduced at x without being ignited by the *continuance* of contact at G or E, but when contact was broken at either place, this wire became red hot proving, by this method, the production of the induced current at that moment

1084 *Chemical decomposition* was next effected by the cross wire current, an electro-magnet being used at D, and a decomposing apparatus, with solution of iodide of potassium in paper (1079), employed at x The conducting power of the connecting system A B D was sufficient to carry all the primary current, and consequently no chemical action took place at x during the *continuance* of contact at G and E, but when contact was broken, there was instantly decomposition at x The iodine appeared against the wire N, and not against the wire P, thus demonstrating that the current through the cross wires, when contact was broken, was in the *reverse direction* to that marked by the arrow, or that which the electromotor would have sent through it

1085 In this experiment a bright spark occurs at the place of disjunction, indicating that only a small part of the extra current passed the apparatus at x, because of the small conducting power of the latter

1086 I found it difficult to obtain the chemical effects with the simple helices and wires, in consequence of the diminished inductive power of these arrangements, and because of the passage of a strong constant current at x whenever a very active electromotor was used (1082)

1087 The most instructive set of results was obtained, however, when the *galvanometer* was introduced at x Using an electro-magnet at D, and continuing contact, a current was then indicated by the deflection, proceeding from P to N, in the direction of the arrow, the cross-wire serving to carry one part of the electricity excited by the electromotor, and that part of the arrangement marked A B D, the other and far greater part, as indicated by the arrows The magnetic needle was then forced back, by pins applied upon opposite sides of its two extremities, to its natural position when uninfluenced by a current, after which, contact being *broken* at G or E, it was deflected strongly in the opposite direction thus showing, in accordance with the chemical effects (1084), that the extra current followed a course in the cross-wires *contrary* to that indicated by the arrow, i e, contrary to the one produced by the direct action of the electromotor [1]

1088 With the *helix* only (1061), these effects could scarcely be observed, in consequence of the smaller inductive force of this arrangement, the opposed action from induction in the galvanometer wire itself, the mechanical condition and tension of the needle from the effect

[1] It was ascertained experimentally that if a strong current was passed through the galvanometer only, and the needle restrained in one direction as above in its natural position when the current was stopped no vibration of the needle in the opposite direction took place

of blocking (1087) whilst the current due to continuance of contact was passing round it and because of other causes With the *extended wire* (1064) all these circumstances had still greater influence and therefore allowed less chance of success

1089 T

erating current and the extra current led me to conclude that the latter was identical with the induced current described (6 26 74) in the first series of these *Researches* and this opinion I was soon able to bring to proof and at the same times obtained not the partial (1078) but entire separation of one current from the other

1090 The double helix (1053) was arranged *so that it should form the connecting wire between the plates of the electromotor* ii being out of the current and its ends unconnected

maining unchanged but now *no spark* or one scarcely sensible could be obtained from the latter at the place of disjunction Then again the ends of ii were held so nearly together that any current running round that helix should be rendered visible as a spark and in this manner a spark was obtained from ii when the junction of i with the electromotor was broken in place of appearing at the disjoined extremity of i itself

1091 By introducing a galvanometer or decomposing apparatus into the circuit formed by the helix ii I could easily obtain the deflections and decomposition occasioned by the in

trary directions of the two induced currents thus produced (26)

1092 All these effects except those of decomposition were reproduced by two extended long wires not having the form of helices but placed close to each other and thus it was

another wire forming a complete circuit be placed parallel to the first at the moment the

first wire induces a current in itself in the same

alent of the current which would be produced in a neighbouring wire if such second current were permitted

1093 Viewing the phenomena as the results of the induction of electrical currents many of the principles of action in the former experiments become far more evident and precise

wire a foot long upon a collateral wire also a foot in length be observed it will be found very small but if the same current be sent through a wire fifty feet long it will induce in a neighbouring wire of fifty feet a far more powerful current at the moment of making or breaking contact each successive foot of wire adding to the sum of action and by parity of reasoning a similar effect should take place when the conducting wire is also that in which the induced current is formed (74) hence the reason why a long wire gives a brighter spark on breaking contact than a short one (1068) although it carries much less electricity

1094 If the long wire be made into a *helix* it will then be still more effective in producing sparks and shocks on breaking contact for by the mutual inductive action of the convolutions each aids its neighbour and will be aided in turn and the sum of effect will be very greatly increased

employed the use con- the so

doing will tend to produce an electric current in the wire around it (37, 38) in conformity with that which the cessation of current in the helix itself also tends to produce

1096 By applying the laws of the induction

current in the two halves shall have opposite actions, it ought not to give a sensible spark at the moment of disjunction and thus proved to be the case, for a wire forty feet long, covered with silk, being doubled and tied closely together to within four inches of the extremities when used in that state, gave scarcely a perceptible spark, but being opened out and the parts separated it gave a very good one The two helices i and ii being joined at their similar ends, and then used at their other extremities to connect the plates of the electromotor, thus constituted one long helix, of which one half was opposed in direction to the other half under these circumstances it gave scarcely a sensible spark, even when the soft iron core was within, although containing nearly two hundred feet of wire When it was made into one consistent helix of the same length of wire it gave a very bright spark

1097 Similar proofs can be drawn from the mutual inductive action of two separate currents (1110) and it is important for the general principles that the consistent action of two such currents should be established Thus two currents going in the same direction should if simultaneously stopped, aid each other by their relative influence or if proceeding in contrary directions, should oppose each other under similar circumstances I endeavoured at first to obtain two currents from two different electromotors, and passing them through the helices i and ii, tried to effect the disjunctions mechanically at the same moment But in this I could not succeed one was always separated before the other, and in that case produced little or no spark, its inductive power being employed in throwing a current round the remaining complete circuit (1090) the current which was stopped last always gave a bright spark If it were ever to become needful to ascertain whether two junctions were accurately broken at the same moment, these sparks would afford a test for the purpose, having an infinitesimal degree of perfection

1098 I was able to prove the points by other expedients Two short thick wires were selected to serve as terminations, by which contact could be made or broken with the electromotor The compound helix, consisting of i and ii (1053), was adjusted so that the extremities of the two helices could be placed in communication with the two terminal wires, in such a manner that the current moving through the thick wires should be divided into two equal portions in the two helices, these portions travelling according to the mode of connexion, either in the same direction or in contrary directions at pleasure In this manner two streams could be obtained, both of which could be stopped simultaneously, because the disjunction could be broken at G or F by removing a single wire When the helices were in contrary directions there was scarcely a sensible spark at the place of disjunction but when they were in accordance there was a very bright one

1099 The helix i was now used constantly, being sometimes associated as above, with helix ii in an according direction and sometimes with helix iii which was placed at a little distance The association i and ii, which presented two currents able to affect each other by induction because of their vicinity gave a brighter spark than the association i and iii, where the two streams could not exert their mutual influence but the difference was not so great as I expected

1100 Thus all the phenomena tend to prove that the effects are due to an inductive action, occurring at the moment when the principal current is stopped I at one time thought they were due to an action continued during the *whole time* of the current, and expected that a steel magnet would have an influence according to its position in the helix comparable to that of a soft iron bar in assisting the effect This, however, is not the case for hard steel, or a magnet in the helix, is not so effectual as soft iron nor does it make any difference how the magnet is placed in the helix, and for very simple reasons namely that the effect does not depend upon a permanent state of the core, but a *change of state*, and that the magnet or hard steel cannot sink through such a difference of state as soft iron, at the moment contact ceases, and therefore cannot produce an equal effect in generating a current of electricity by induction (34, 37)

1101 As an electric current acts by induction with equal energy at the moment of its commencement as at the moment of its cessation (10 26), but in a contrary direction, the reference of the effects under examination to an inductive action would lead to the conclusion that corresponding effects of an opposite nature must occur in a long wire, a helix, or an electro-magnet, every time that *contact is made* with the electromotor These effects will tend to establish a resistance for the first moment in the long conductor, producing a result equivalent to the reverse of a shock or a spark. Now

it is very difficult to devise means fit for the *recognition of such negative results*, but as it is probable that some positive effect is produced at the time, if we knew what to expect, I think the few facts bearing upon this subject with which I am acquainted are worth recording

1102 The electro magnet was arranged with an electrolyzing apparatus at x, as before described (1084), *except that the intensity of the* chemical action at the electromotor was increased until the electric current was just able to produce the feeblest signs of decomposition whilst contact was continued at G and E (1079) (the iodine of course appearing against the end of the cross-wire P) the wire N was also separated from A at r, so that contact there could be made or broken at pleasure Under these circumstances the following set of actions was repeated several times contact was broken at r, then broken at G, next made at r, and lastly renewed at G, thus any current from N to P due to *breaking* of contact was avoided but any additional force to the current from P to N due to *making* contact could be observed In this way it was found that a much greater decomposing effect (causing the evolution of iodine against P) could be obtained by a few completions of contact than by the current which could pass in a much longer time if the contact was *continued* This I attribute to the act of induction in the wire A B D at the moment of contact rendering that wire a worse conductor, or rather retarding the passage of the electricity through it for the instant, and so throwing a greater quantity of the electricity which the electromotor could produce through the cross wire passage N P The *instant the induction* ceased, A B D resumed its full power of carrying a constant current of electricity, and could have it highly increased, as we know by the former experiments (1060) by the opposite inductive action brought into activity at the moment contact at Z or C was *broken*

1103 A galvanometer was then introduced at x, and the deflection of the needle noted whilst contact was continued at G and E the needle was then blocked as before in one direction (1087), so that it should not return when the current ceased, but remain in the position in which the current could retain it Contact at G or E was broken, producing of course no visible effect, it was then renewed, and the needle was instantly deflected, passing [illegible] ing pins to a [illegible] ural pla[illegible] could give, and thus showing, by the temporary excess of current in this cross communication, the temporary retardation in the circuit A B D

1104 On adjusting a platina wire at x (1081) so that it should not be ignited by the current passing through it whilst contact at G and E was *continued*, and yet become red hot by a current somewhat more powerful, I was readily *able to produce its ignition upon making contact*, and again upon *breaking contact* Thus the momentary retardation in A B D on making contact was again shown by this result, as well also as the opposite result upon breaking contact The two ignitions of the wire at x were of course produced by electric currents moving in *opposite directions*

1105 Using the *helix* only, I could not obtain distinct deflections at x, due to the extra effect on making contact, for the reasons *already mentioned (1088)* By using a very fine platina wire there (1083), I did succeed in obtaining the igniting effect for making contact *in the same manner*, though by *no means* to the same degree, as with the electro-magnet (1104)

1106 We may also consider and estimate the *effect on making contact*, by transferring the force of induction from the wire carrying the original current to a lateral wire, as in the cases described (1090), and we then are sure, both by the chemical and galvanometrical results (1091), that the forces upon making and breaking contact, *like action and reaction are equal in their strength but contrary* in their direction If, therefore, the effect on making contact resolves itself into a mere retardation of the *current at the first moment* of its existence, it must be, in its degree equivalent to the high exaltation of that same current at the moment contact is broken

1107 Thus the case, under the circumstances is that the intensity and quantity of electricity moving in a current are smaller when the current commences or is increased, and greater when it diminishes or ceases, than they would be if the inductive action occurring at these *moments did not take place* or than they are in the original current wire if the inductive action be transferred from that wire to a collateral one (1090)

1108 From the facility of transference to neighbouring wires, and from the effects generally, the inductive forces appear to be lateral, i e , exerted in a direction perpendicular to the direction of the originating and produced cur-

rents and they also appear to be accurately represented by the magnetic curves, and closely related to, if not identical with, magnetic forces

1109 There can be no doubt that the current in one part of a wire can act by induction upon other parts of the *same* wire which are lateral to the first, i e, in the same vertical section (74), or in the parts which are more or less oblique to it (1112), just as it can act in producing a current in a neighbouring wire or in a neighbouring coil of the same wire It is this which gives the appearance of the current acting upon itself but all the experiments and all analogy tend to show that the elements (if I may so say) of the currents do not act upon themselves, and so cause the effect in question, but produce it by exciting currents in conducting matter which is lateral to them

1110 It is possible that some of the expressions I have used may seem to imply that the inductive action is essentially the action of one current upon another, or of one element of a current upon another element of the same current. To avoid any such conclusion I must explain more distinctly my meaning If an endless wire be taken, we have the means of generating a current in it which shall run round the circuit without adding any electricity to what was previously in the wire As far as we can judge, the electricity which appears as a current is the same as that which before was quiescent in the wire, and though we cannot as yet point out the essential condition of difference of the electricity at such times we can easily recognize the two states. Now when a current acts by induction upon conducting matter lateral to it, it probably acts upon the electricity in that conducting matter whether it be in the form of a *current* or *quiescent* in the one case increasing or diminishing the current according to its direction, in the other producing a current, and the *amount* of the inductive action is probably the same in both cases Hence, to say that the action of induction depended upon the mutual relation of two or more currents would, according to the restricted sense in which the term current is understood at present (283, 517, 667) be an error

1111 Several of the effects, as for instances, those with helices (1066), with according or counter currents (1097, 1098), and those on the production of lateral currents (1090), appeared to indicate that a current could produce an effect of induction in a neighbouring wire more readily than in its own carrying wire, in which case it might be expected that some variation of result would be produced if a bundle of wires were used as a conductor instead of a single wire In consequence the following experiments were made A copper wire one twenty third of an inch in diameter was cut into lengths of five feet each, and six of these being laid side by side in one bundle had their opposite extremities soldered to two terminal pieces of copper This arrangement could be used as a discharging wire, but the general current could be divided into six parallel streams which might be brought close together or, by the separation of the wires, be taken more or less out of each other's influence A somewhat brighter spark was, I think obtained on breaking contact when the six wires were close together than when held asunder

1112 Another bundle, containing twenty of these wires, was eighteen feet long the terminal pieces were one-fifth of an inch in diameter, and each six inches long This was compared with nineteen feet in length of copper wire one-fifth of an inch in diameter The bundle gave a smaller spark on breaking contact than the latter, even when its strands were held together by string when they were separated, it gave a still smaller spark Upon the whole, however, the diminution of effect was not such as I expected and I doubt whether the results can be considered as any proof of the truth of the supposition which gave rise to them.

1113 The inductive force by which two elements of one current (1109, 1110) act upon each other appears to diminish as the line joining them becomes oblique to the direction of the current and to vanish entirely when it is parallel I am led by some results to suspect that it then even passes into the repulsive force noticed by Ampère [1] which is the cause of the elevations in mercury described by Sir Humphry Davy,[2] and which again is probably directly connected with the quality of intensity

1114 Notwithstanding that the effects appear only at the making and breaking of contact (the current remaining unaffected, seemingly, in the interval), I cannot resist the impression that there is some connected and correspondent effect produced by this lateral action of the elements of the electric stream during the time of its continuance (60, 242) An action of this kind, in fact is evident in the magnetic relations of the parts of the current. But admitting (as we may do for the moment)

[1] *Recueil d'Observations Electro-Dynamiques* p 285.
[2] *Philosophical Transactions* 1823 p 155

the magnetic forces to constitute the power which produces such striking and different results at the commencement and termination of a current, still there appears to be a link in the chain of effects, a wheel in the physical mechanism of the action, as yet unrecognised If we endeavour to consider electricity and magnetism as the results of two forces of a physical agent, or a peculiar condition of matter, exerted in determinate directions perpendicular to each other, then, it appears to me, that we must consider these two states or forces as convertible into each other in a greater or smaller degree, i e, that an element of an electric current has not a determinate electric force and a determinate magnetic force constantly existing in the same ratio, but that the two forces are,

a state which, when allowed to react, (at the

tric force and if it result from a change of electrical into magnetic force, and a reconversion back again, *it will show that they differ in*

1115 With reference to the appearance at different times, of the contrary effects produced by the making and breaking contact, and their separation by an intermediate and indifferent state, this separation is probably more apparent than real If the conduction of electricity be effected by vibrations (283), or by any other

in the same way, may be very important and, for instance, perhaps constitute the very es-

enter, more minutely than I otherwise should have done, into the experimental examination of the phenomena described in this paper

1116 Before concluding, I may briefly remark that on using a voltaic battery of fifty pairs of plates instead of a single pair (1052), the effects were exactly of the same kind The spark on making contact, for the reasons before given, was very small (1101, 1107), that on breaking contact, very excellent and brilliant The *continuous* discharge did not seem altered in character, whether a short wire or the powerful electro-magnet were used as a connecting discharger

1117 The effects produced at the commencement and end of a current (which are separated by an interval of time when that current is sup-

whether they would not still give some definite peculiarity to the discharge, is a matter remaining to be examined but it is very probable that the peculiar character and pungency of sparks drawn from a long wire depend in part upon the increased intensity given at the *termination of the discharge* by the inductive action then occurring

1118 In the wire of the helix of magneto-electric machines (as, for instance, in Mr Saxton's beautiful arrangement), an important influence of these principles of action is evidently shown From the construction of the apparatus the current is permitted to move in a complete metallic circuit of great length during the first instants of its formation it gradually rises in

tus could produce if the principle which forms the subject of this paper were not called into play

Royal Institution, December 8, 1834

TENTH SERIES

§ 16 *On an Improved Form of the Voltaic Battery* § 17 *Some Practical Results Respecting the Construction and Use of the Voltaic Battery*

RECEIVED JUNE 16 READ JUNE 18 1835

1119 I HAVE lately had occasion to examine

to the discovery of a new law or principle I still think they are valuable and may therefore if briefly told and in connexion with former papers be worthy the approbation of the Royal Society

§ 16 *On an Improved Form of the Voltaic Battery*

1120 In a simple voltaic circuit (and the same is true of the battery) the chemical forces which during their activity give power to the

instrument whilst the former is altogether lost or wasted The ratio of these two portions of power may be varied to a great extent by the influence of circumstances thus in a battery not closed *all* the action is local in one of the

all the chemical power circulates and becomes electricity By referring to the quantity of zinc dissolved from the plates (865 1126) and the quantity of decomposition effected in the volta-electrometer (711 1126) or elsewhere the proportions of the local and transferred actions under any particular circumstances can be ascertained and the efficacy of the voltaic arrangement or the waste of chemical power at its zinc plates be accurately determined

1121 If a voltaic battery were constructed of zinc and platina the latter metal surrounding the former as in the double copper arrangement and the whole being excited by

provided these did not touch metallically the same acid which being between the zinc and platina would excite the battery into powerful action would between the two surfaces of

sity of Pennsylvania to whom I have great pleasure in referring it

1124 Dr Hare has fully described his trough [1]

[1] *Philosophical Magazine* 1824 Vol LXIII p 241 or *Silliman's Journal* Vol VII See also a previous paper by Dr Hare *Annals of Philosophy* 1821 Vol I p 329 in which he speaks of the non necessity of insulation between the coppers

In it the contiguous copper plates are separated by thin veneers of wood, and the acid is poured on to, or off, the plates by a quarter revolution of an axis, to which both the trough containing the plates, and another trough to collect and hold the liquid, are fixed This arrangement I have found the most convenient of any, and have therefore adopted it My zinc plates were cut from rolled metal, and when soldered to the copper plates had the form delineated, *Fig 1* These were then bent over a



Fig 1

gauge into the form *Fig 2*, and when packed in the wooden box constructed to receive them, were arranged as in *Fig 3*,[1] little plugs of cork



Fig 2

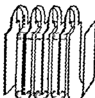


Fig 3

being used to keep the zinc plates from touching the copper plates, and a single or double thickness of cartridge paper being interposed between the contiguous surfaces of copper to prevent them from coming in contact Such was the facility afforded by this arrangement, that a trough of forty pairs of plates could be unpacked in five minutes, and repacked again in half an hour, and the whole series was not more than fifteen inches in length

1125 This trough, of forty pairs of plates three inches square, was compared, as to the ignition of a platina wire, the discharge between points of charcoal, the shock on the human frame, &c, with forty pairs of four-inch plates having double coppers, and used in porcelain troughs divided into insulating cells, the strength of the acid employed to excite both being the same In all these effects the former appeared quite equal to the latter On comparing a second trough of the new construction, containing twenty pairs of four inch plates, with twenty pairs of four inch plates in porcelain troughs, excited by acid of the same strength, the new trough appeared to surpass the old one in producing these effects, especially in the ignition of wire

[1] The papers between the coppers are for the sake of distinctness omitted in the figure

1126 In these experiments the new trough diminished in its energy much more rapidly than the one on the old construction, and this was a necessary consequence of the smaller quantity of acid used to excite it, which in the case of the forty pairs of new construction was only one seventh part of that used for the forty pairs in the porcelain troughs To compare therefore, both forms of the voltaic trough in their decomposing powers, and to obtain accurate data as to their relative values experiments of the following kind were made The troughs were charged with a known quantity of acid of a known strength the electric current was passed through a volta-electrometer (711) having electrodes 4 inches long and 2 3 inches in width, so as to oppose as little obstruction as possible to the current, the gases evolved were collected and measured, and gave the quantity of water decomposed Then the whole of the charge used was mixed together, and a known part of it analysed, by being precipitated and boiled with excess of carbonate of soda, and the precipitate well washed, dried, ignited, and weighed In this way the quantity of metal oxidized and dissolved by the acid was ascertained, and the part removed from each zinc plate, or from all the plates, could be estimated and compared with the water decomposed in the volta-electrometer To bring these to one standard of comparison, I have reduced the results so as to express the loss at the plates in equivalents of zinc for the equivalent of water decomposed at the volta-electrometer I have taken the equivalent number of water as 9, and of zinc as 32 5, and have considered 100 cubic inches of the mixed oxygen and hydrogen, as they were collected over a pneumatic trough, to result from the decomposition of 12 68 grains of water

1127 The acids used in these experiments were three sulphuric, nitric, and muriatic The sulphuric acid was strong oil of vitriol one cubical inch of it was equivalent to 486 grains of marble The nitric acid was very nearly pure one cubical inch dissolved 150 grains of marble The muriatic acid was also nearly pure, and one cubical inch dissolved 108 grains of marble These were always mixed with water by volumes, the standard of volume being a cubical inch

1128 An acid was prepared consisting of 200 parts water, 4½ parts sulphuric acid, and 4

parts nitric acid and with this both my trough containing forty pairs of three-inch plates, and four porcelain troughs, arranged in succession, each containing ten pairs of plates with double coppers four inches square were charged These two batteries were then used in succession and the action of each was allowed to continue for twenty or thirty minutes until the charge was nearly exhausted, the connexion with the volta electrometer being carefully preserved during the whole time, and the acid in the troughs occasionally mixed together In this way the former trough acted so well, that for each equivalent of water decomposed in the volta-electrometer only from 2 to 2 5 equivalents of zinc were dissolved from each plate In four experiments the average was 2 21 equivalents for each plate, or 88 4 for the whole battery In the ex-

lent for each zinc plate or forty for the whole

1129 Similar experiments were made with two voltaic batteries one containing twenty pairs of four inch plates arranged as I have

each plate, or 74 from the whole the average of three experiments with the latter was 5 5 equivalents from each plate or 110 from the whole to obtain this conclusion two experiments were struck out which were much against

plates together, as that would have introduced serious errors into the conclusions (1146)

1130 When ten pairs of the new arrangement were used, the consumption of zinc at each plate was 6 76 equivalents or 67 6 for the whole With ten pairs of the common construction in a porcelain trough the zinc oxidized was upon an average 15.5 equivalents for each plate, or 155 for the entire trough

1131 No doubt, therefore can remain of the equality or even the great superiority of this form of voltaic battery over the best previously

and it is that circumstance which p

permits of such other alterations in the construction of the trough as gives it its practical advantages

1132 The advantages of this form of trough are very numerous and great i It is exceedingly compact for 100 pairs of plates need not oc-

tions and these I have found it very convenient to connect with two cups of mercury, fastened in the front of the stand of the instrument These fixed terminations give the great advantage of arranging an apparatus to be used in connexion with the battery *before* the latter is put into action iii The trough is put

which the battery can produce a minute or two after (1036 1150) v When the experiment is completed the acid can be at once poured from between the plates so that the battery is never left to waste during an unconnected state of its extremities the acid is not unnecessarily

the zinc and copper plates may be brought much nearer to each other when the battery is

rolled zinc superior to cast zinc in action a superiority which I incline to attribute to its greater purity (1144) ix Another advantage is obtained in the economy of the acid used, which is proportionate to the diminution of the zinc dissolved x The acid also is more easily exhausted, and is in such small quantity that there is never any occasion to return an old charge into use The acid of old charges whilst out of use, often dissolves portions of copper from the black *flocculi* usually mingled with it, which are derived from the zinc now any portion of copper in solution in the charge does great harm, because, by the *local* action of the acid and zinc, it tends to precipitate upon the latter, and diminish its voltaic efficacy (1145) xi By using a due mixture of nitric and sulphuric acid for the charge (1139), no gas is evolved from the troughs so that a battery of several hundred pairs of plates may without inconvenience, be close to the experimenter xii If, during a series of experiments the acid becomes exhausted it can be withdrawn and replaced by other acid with the utmost facility and after the experiments are concluded the great advantage of easily washing the plates is at command And it appears to me that in place of making under different circumstances, mutual sacrifices of comfort power and economy, to obtain a desired end all are at once obtained by Dr Hare s form of trough

1133 But there are some disadvantages which I have not yet had time to overcome, though I trust they will finally be conquered One is the extreme difficulty of making a wooden trough constantly water-tight under the alternations of wet and dry to which the voltaic instrument is subject To remedy this evil Mr Newman is now engaged in obtaining porcelain troughs The other disadvantage is a precipitation of copper on the zinc plates It appears to me to depend mainly on the circumstance that the papers between the coppers retain acid when the trough is emptied and that this acid slowly acting on the copper forms a salt which gradually mingles with the next charge and is reduced on the zinc plate by the local action (1120) the power of the whole battery is then reduced I expect that by using slips of glass or wood to separate the coppers at their edges, their contact can be sufficiently prevented and the space between them be left so open that the acid of a charge can be poured and washed out and so be removed from *every part* of the trough when the experiments in which the latter is used are completed

1134 The actual superiority of the troughs which I have constructed on this plan, I believe to depend, first and principally, on the closer approximation of the zinc and copper surfaces, in my troughs they are only one-tenth of an inch apart (1148) and next, on the superior quality of the rolled zinc above the cast zinc used in the construction of the ordinary pile It cannot be that insulation between the contiguous coppers is a disadvantage but I do not find that it is any advantage, for when with both the forty pairs of three-inch plates and the twenty pairs of four inch plates I used papers well-soaked in wax,[1] these being so large that when folded at the edges they wrapped over each other, so as to make cells as insulating as those of the porcelain troughs, still no sensible advantage in the chemical action was obtained

1135 As upon principle, there must be a discharge of part of the electricity *from the edges of the zinc and copper plates at the sides of the trough, I should prefer, and intend having troughs constructed with a plate or plates* of crown glass at the sides of the trough the bottom will need none though to glaze that and the ends would be no disadvantage The plates need not be fastened in but only set in their places nor need they be in large single pieces

§ 17 *Some Practical Results Respecting the Construction and Use of the Voltaic Battery* (1034 &c)

1136 The electro-chemical philosopher is well acquainted with some practical results obtained from the voltaic battery by MM Gay Lussac and Thenard, and given in the first forty five pages of their *Recherches Physico-Chimiques* Although the following results are generally of the same nature yet the advancement made in this branch of science of late years the knowledge of the *definite action* of electricity, and the more accurate and philosophical mode of estimating the results by the *equivalents of zinc consumed*, will be their sufficient justification

1137 *Nature and strength of the acid* My battery of forty pairs of three-inch plates was charged with acid consisting of 200 parts water and 9 oil of vitriol Each plate lost, in the average of the experiments 4 66 equivalents of zinc for the equivalent of water decomposed in the volta-electrometer, or the whole battery

[1] A single paper thus prepared could insulate the electricity of a trough of forty pairs of plates.

186 4 equivalents of zinc Being charged with a mixture of 200 water and 16 of the muriatic acid, each plate lost 3 8 equivalents of zinc for the water decomposed, or the whole battery 152 equivalents of zinc Being charged with a mixture of 200 water and 8 nitric acid, each plate lost 1 85 equivalents of zinc for one equivalent of water decomposed, or the whole battery 74 16 equivalents of zinc The sulphuric and

difference in that respect makes no important difference in the results when thus expressed by equivalents (1140)

and

sequently, be expected to improve sulphuric and muriatic acids Accordingly, when the same trough was charged with a mixture of 200 water, 9 oil of vitriol, and 4 nitric acid, the consumption of zinc was at each plate 2 786, and for the whole battery 111 5, equivalents

loss per plate was 2 11, or for the whole bat-

and 4 nitric acid

1140 It is not to be supposed that the different strengths of the acids produced the differences above for within certain limits I found the electrolytic effects to be nearly as the strengths of the acids, so as to leave the ex-

lent When it was 200 water and 32 nitric acid, the loss was 2 1 equivalents The differences here are not greater than happen from unavoidable irregularities, depending on other causes than the strength of acid

1141 Again, when a charge consisting of 200 water, 4½ oil of vitriol, and 4 nitric acid was used, each zinc plate lost 2 16 equivalents, when the charge with the same battery was 200 water, 9 oil of vitriol, and 8 nitric acid, each zinc plate lost 2 26 equivalents

1142 I need hardly say that no copper is dissolved during the regular action of the voltaic trough I have found that much ammonia is formed in the cells when nitric acid either pure

important point, as I have already shown experimentally (1042, &c) Hence one great advantage of Dr Hare s mechanical arrangement of his trough

1144 *Purity of the zinc* If pure zinc could be

acid leave more or less of an insoluble matter upon the surface in the form of a crust, which contains various metals, as copper, lead, zinc, iron, cadmium &c , in the metallic state Such particles, by discharging part of the transferable power, render it as to the whole battery, local and so diminish the effect As an indication connected with the more or less perfect

transferable force The investing crust is also

the purest and to the circumstance of having used such zinc in its construction attribute in

pecially if they are employed to obtain the laws of action of the battery itself Thus pre-

caution was *always attended* to with the porcelain trough batteries in the experiments described (1125, &c) If a few foul plates are mingled with many clean ones, they make the action in the different cells irregular, and the transferable power is accordingly diminished, whilst the local and wasted power is increased No old charge containing copper should be used to excite a battery

1146 *New and old plates* I have found voltaic batteries far more powerful when the plates were new than when they have been used two or three times, so that a new and a used battery cannot be compared together, or even a battery *with itself* on the first and after times of use My trough of twenty pairs of four-inch plates, charged with acid consisting of 200 water, 4½ oil of vitriol, and 4 nitric acid, lost, upon the first time of being used, 2 32 equivalents per plate. When used after the fourth time with the same charge, the loss was from 3 26 *to* 4 47 *equivalents per plate*, the average being 3 7 equivalents The first time the forty pair of plates (1124) were used the loss at each plate was only 1 65 equivalent, but afterwards it became 2 16, 2 17, 2 52 The first time twenty pair of four inch plates in porcelain troughs were used, they lost, per plate, only 3 7 equivalents, *but after that, the loss was* 5 25, 5 36, 5 9 equivalents Yet in all these cases the zincs had been well-cleaned from adhering copper, &c, before each trial of power

1147 With the rolled zinc the fall in force soon appeared to become constant, i e., to proceed no further But with the cast zinc plates belonging to the porcelain troughs, it appeared to continue, until at last, with the same charge, each plate lost above *twice as much zinc* for a given amount of action as at first These troughs were, however, so irregular that I could not always determine the circumstances affecting the amount of electrolytic action

1148 *Vicinity of the copper and zinc* The importance of this point in the construction of voltaic arrangements, and the greater power, as to immediate action, which is obtained when the zinc and copper surfaces are near to each other than when removed farther apart, are well known *I find that the power is not only* greater on the instant, but also that the sum of transferable power, in relation to the whole sum of chemical action at the plates, is much increased The cause of this gain is very evident Whatever tends to retard the circulation of the transferable force (i e, the electricity) *diminishes* the proportion of such force, and increases the proportion of that which is local (996, 1120) Now the liquid in the cells possesses this retarding power, and therefore acts injuriously, in greater or less proportion according to the quantity of it between the zinc and copper plates, *i e, according to the distances* between their surfaces A trough, therefore, in which the plates are only *half* the distance asunder at which they are placed in another, will produce more transferable and less local, force than the latter, and thus because the electrolyte in the cells can transmit *the current more readily*, both the intensity and quantity of electricity is increased for a given consumption of zinc To this circumstance mainly I attribute the superiority of the trough I have described (1134)

1149 The superiority of *double coppers* over single plates also depends in part upon diminishing the resistance offered by the electrolyte between the metals For, in fact with double coppers the sectional area of the interposed acid becomes nearly double that with single coppers, and therefore it more freely transfers the electricity Double coppers are however effective, mainly because they virtually double the acting surface of the zinc, or nearly so, for in a trough with single copper plates and the *usual construction of cells*, that surface of zinc which is not opposed to a copper surface is thrown almost entirely out of voltaic action yet the acid continues to act upon it and the metal is dissolved, producing very little more than local effect (947, 996) But when by doubling the copper, that metal is opposed to the second surface of the zinc plate, then a great part of the action upon the latter is converted into transferable force, and thus the power of the trough as to quantity of electricity is highly exalted.

1150 *First immersion of the plates* The great effect produced at the first immersion of the plates (apart from their being new or used [1146]) I have attributed elsewhere to the unchanged condition of the acid in contact with the zinc plate (1003, 1037) as the acid becomes neutralized, its exciting power is proportionably diminished Hare's form of trough secures much advantage of this kind, by mingling the liquid, and bringing what may be considered as a fresh surface of acid against the plates every time it is used *immediately after a rest*.

1151 *Number of plates*[1] The most advantageous number of plates in a battery used for chemical decomposition depends almost en-

[1] Gay Lussac and Thenard *Recherches Physico-Chimiques* Vol I p 29

tirely upon the resistance to be overcome at the place of action but whatever that resistance may be, there is a certain number which is more economical than either a greater or a less Ten pairs of four-inch plates in a porcelain trough of the ordinary construction, acting in the *volta-electrometer (1126)* upon dilute sulphuric acid of spec grav 1.314, gave an average consumption of 15 4 equivalents per plate, or 154 *equivalents on the whole* Twenty pairs of the same plates, with the same acid gave only a consumption of 5 5 per plate, or 110 equivalents upon the whole When forty pairs of the same plates were used, the consumption was 3 54 equivalents per plate, or 141 6 upon the whole battery Thus the consumption of

equivalent of zinc, in effecting decomposition, whilst twenty pairs of the same plates, excited by the same acid, lost 3 7 equivalents each, or

number of plates which would produce the most advantageous effect would have risen or if I had used a better conductor than that really employed in the volta-electrometer, I might have reduced the number even to one as, for instance, when a thick wire is used to complete the circuit (865, &c) And the cause of these variations is very evident, when it is considered that each successive plate in the voltaic apparatus does not add anything to the *quantity* of transferable power or electricity which the first plate can put into motion, provided a good conductor be present, but tends only to

[1] Gay Lussac and Thenard *Recherches Physico-Chimiques* Vol I p 29

zations will evidently depend upon the facility with which the transferable power of electricity can pass If in a particular case the most effectual number of plates is known (1151), then the addition of more zinc would be most advantageously made in increasing the *size* of the plates, and not their *number* At the same time, large increase in the size of the plates would raise in a small degree the most favourable number

whole consumption of zinc was 88 4 equivalents, and in the second only 48 28 equivalents, for the whole of the water decomposed in both volta-electrometers

1157 But when the twenty pairs of four inch plates (1129) were tried in a similar manner, the results were in the opposite direction With one volta-electrometer 52 cubic inches of gas were obtained with two, only 14 6 cubic

metal in the first case was 71, and in the second case 97, equivalents for the *whole* of the water decomposed These results of course depend

ally called *conducting, power* of an electrolyte

[2] Gay Lussac and Thenard *Recherches Physico-Chimiques* Vol I pp 13 15 22

the electricity is passed, i e, *nearly all* the chemical power becomes transferable, even with a single pair of plates (867) With an interposed non conductor none of the chemical power becomes transferable With an imperfect conductor more or less of the chemical power becomes transferable as the circumstances favouring the transfer of forces across the imperfect conductor are exalted or diminished these circumstances are actual increase or improvement of the conducting power, enlargement of the electrodes, approximation of the electrodes, and increased intensity of the passing current

1159 The introduction of common spring water in place of one of the volta-electrometers used with twenty pairs of four inch plates (1156) caused such obstruction as not to allow one-fifteenth of the transferable force to pass which would have circulated without it Thus fourteen fifteenths of the available force of the battery were destroyed, being converted into local force (which was rendered evident by the evolution of gas from the zincs), and yet the platina electrodes in the water were three inches long, nearly an inch wide, and not a quarter of an inch apart

1160 These points, i e., the increase of conducting power, the enlargement of the electrodes, and their approximation, should be especially attended to in *volta-electrometers* The principles upon which their utility depend are so evident that there can be no occasion for further development of them here

Royal Institution, October 11, 1834

ELEVENTH SERIES

§ 18 *On Induction* ¶ i *Induction an Action of Contiguous Particles* ¶ ii *On the Absolute Charge of Matter* ¶ iii *Electrometer and Inductive Apparatus Employed* ¶ iv *Induction in Curved Lines* ¶ v *On Specific Induction, or Specific Inductive Capacity* ¶ vi *General Results as to Induction*

RECEIVED NOVEMBER 30, READ DECEMBER 21, 1837

¶ i *Induction an Action of Contiguous Particles*

1161 THE science of electricity is in that state in which every part of it requires experimental investigation not merely for the discovery of new effects, but what is just now of far more importance, the development of the means by which the old effects are produced, and the consequent more accurate determination of the first principles of action of the most extraordinary and universal power in nature and to those philosophers who pursue the inquiry zealously yet cautiously, combining experiment with analogy, suspicious of their preconceived notions, paying more respect to a fact than a theory, not too hasty to generalize, and above all things, willing at every step to cross-examine their own opinions, both by reasoning and experiment, no branch of knowledge can afford so fine and ready a field for discovery as this Such is most abundantly shown to be the case by the progress which electricity has made in the last thirty years chemistry and magnetism have successively acknowledged its over-ruling influence and it is probable that every effect depending upon the powers of inorganic matter, and perhaps most of those related to vegetable and animal life, will ultimately be found subordinate to it

1162 Amongst the actions of different kinds into which electricity has conventionally been subdivided, there is, I think, none which excels, or even equals in importance that called *induction*. It is of the most general influence in electrical phenomena, appearing to be concerned in every one of them and has in reality the character of a first, essential, and fundamental principle Its comprehension is so important that I think we cannot proceed much further in the investigation of the laws of electricity without a more thorough understanding of its nature how otherwise can we hope to comprehend the harmony and even unity of action which doubtless governs electrical excitement by friction, by chemical means by heat, by magnetic influence, by evaporation, and even by the living being?

1163 In the long-continued course of experimental inquiry in which I have been engaged, this general result has pressed upon me constantly, namely, the necessity of admitting two

forces, or two forms or directions of a force (516, 517), combined with the impossibility of separating these two forces (or electricities) from each other, either in the phenomena of statical electricity or those of the current In association with this, the impossibility under any circumstances, as yet, of absolutely charging matter of any kind with one or the other

electrical powers and the particles of matter are related, especially in inductive actions, upon which almost all others appeared to rest

1164 When I discovered the general fact that electrolytes refused to yield their elements to a current when in the solid state, though they gave them forth freely if in the liquid con

phenomena to one law For let the electrolyte be water, a plate of ice being coated with platina foil on its two surfaces, and these coatings connected with any continued source of the two electrical powers, the ice will charge like a Leyden arrangement, presenting a case of common induction, but no current will pass If the ice be liquefied, the induction will fall to a cer-

ing be effected by a powerful electrical ma-

the electrolyte be solid, or if fluid, chemical action and decomposition ensue, provided opposing actions do not interfere, and it is of

was the same in its nature as that through air, glass, wax, &c , produced by any of the ordinary means, and as the whole effect in the electrolyte appeared to be an action of the particles thrown into a peculiar or polarized state, I was led to suspect that common induction itself was in all cases an *action of contiguous particles*,[1] and that electrical action at a distance (i e., ordinary inductive action) never occurred except through the influence of the intervening matter

1165 The respect which I entertain towards the names of Epinus, Cavendish, Poisson, and other most eminent men, all of whose theories I believe consider induction as an action at a

must be of the greatest consequence to our further progress in the investigation of the na-

tion, the transfer of elements in an electrolyte,

perhaps not the best that

those which would not be consistent with the theory of action at a distance Such a consequence seemed to me to present itself in the *direction in which inductive action* could be exerted If in straight lines only, though not perhaps decisive, it would be against my view, but if in curved lines also, that would be a natural result of the action of contiguous particles, but, as I think, utterly incompatible with action at a distance, as assumed by the received theories, which, according to every fact and analogy we are acquainted with, is always in straight lines

1167 Again if induction be an action of contiguous particles, and also the first step in the process of electrolyzation (949, 1164), there seemed reason to expect some particular relation of it to the different kinds of matter through which it would be exerted, or something equivalent to a *specific electric induction* for different bodies, which, if it existed would unequivocally prove the dependence of induction on the particles, and though this, in the theory of Poisson and others, has never been supposed to be the case, I was soon led to doubt the received opinion, and have taken great pains in subjecting this point to close experimental examination

1168 Another ever present question on my mind has been, whether electricity has an actual and independent existence as a fluid or fluids, or was a mere power of matter, like what we conceive of the attraction of gravitation If determined either way it would be an enormous advance in our knowledge, and as having the most direct and influential bearing on my notions, I have always sought for experiments which would in any way tend to elucidate that great inquiry It was in attempts to prove the existence of electricity separate from matter, by giving an independent charge of either positive or negative power only, to some one substance, and the utter failure of all such attempts, whatever substance was used or whatever means of exciting or evolving electricity were employed, that first drove me to look upon induction as an action of the particles of matter, each having both forces developed in it in exactly equal amount It is this circumstance, in connexion with others, which makes me desirous of placing the remarks on absolute charge first, in the order of proof and argument, which I am about to adduce in favour of my view, that electric induction is an action of the contiguous particles of the insulating medium or *dielectric*[1]

[1] I use the word *dielectric* to express that substance through or across which the electric forces are acting —*Dec* 1838.

¶ ii *On the Absolute Charge of Matter*

1169 Can matter, either conducting or non conducting, be charged with one electric force independently of the other, in any degree, either in a sensible or latent state?

1170 The beautiful experiments of Coulomb upon the *equality of action of conductors*, whatever their substance, and the residence of *all* the electricity upon their surfaces[1] are sufficient, if properly viewed, to prove that *conductors cannot be bodily charged*, and as yet no means of communicating electricity to a conductor so as to place its particles in relation to one electricity, and not at the same time to the other in exactly equal amount, has been discovered

1171 With regard to electrics or non-conductors, the conclusion does not at first seem so clear They may easily be electrified bodily, either by communication (1247) or excitement, but being so charged, every case in succession, when examined, came out to be a case of induction, and not of absolute charge Thus, glass within conductors could easily have parts not in contact with the conductor brought *into* an excited state but it was always found that a portion of the inner surface of the conductor was in an opposite and equivalent state, or that another part of the glass itself was in an equally opposite state, an *inductive* charge and not an *absolute* charge having been acquired

1172 Well purified oil of turpentine, which I find to be an excellent liquid insulator for most purposes, was put into a metallic vessel and, being insulated, an endeavour was made to charge its particles, sometimes by contact of the metal with the electrical machine, and at others by a wire dipping into the fluid within, but whatever the mode of communication, no electricity of one kind only was retained by the arrangement, except what appeared on the exterior surface of the metal, that portion being present there only by an inductive action through the air to the surrounding conductors When the oil of turpentine was confined in glass vessels, there were at first some appearances as if the fluid did receive an absolute charge of electricity from the charging wire, but these were quickly reduced to cases of common induction jointly through the fluid, the glass, and the surrounding air

1173 I carried these experiments on with air to a very great extent I had a chamber built, being a cube of twelve feet A slight cu-

[1] *Mémoires de l Académie*, 1786, pp. 67, 69 72 1787, p 452

bical wooden frame was constructed, and cop-

supplied in every direction with bands of tin foil, that the whole might be brought into good metallic communication, and rendered a free conductor in every part This chamber was in sulated in the lecture-room of the Royal Insti

of a room in which a powerful machine is in operation), and at the same time the outside of the insulated cube was everywhere strongly

moment or instantly after insulated the cube, the air within had not the least power to communicate a further charge to it If any portion of the air was electrified, as glass or other in-

either electricity failed

tricity I charged and discharged the whole arrangement in various ways, but in no case could I obtain the least indication of an absolute charge or of one by induction in which the electricity of one kind had the smallest superiority in quantity over the other I went into the cube and lived in it and using lighted can dles electrometers and all other tests of elec-

part of its outer surface The conclusion I have come to is that non-conductors, as well as conductors have never yet had an absolute and independent charge of one electricity communicated to them and that to all appearance such a state of matter is impossible

1175 There is another view of this question which may be taken under the supposition of the existence of an electric fluid or fluids It may be impossible to have one fluid or state in a free condition without its producing by in duction the other and yet possible to have cases in which an isolated portion of matter in one condition being uncharged shall, by a change of state evolve one electricity or the other

would be a very important fact in the theories which assume a fluid or fluids these theories as I understand them assigning not the slightest reason why such an effect should not occur

1176 But on searching for such cases I cannot find one Evolution by friction as is well

may be employed and the enormous quantity of electricity which can in this manner be evolved (371 376 861 868, 961) The more promising cases of change of state whether by evapora tion, fusion, or the reverse processes still give both forms of the power in *equal* proportion, and the cases of splitting of mica and other crystals the breaking of sulphur, &c., are subject to the same law of limitation

1177 As far as experiment has proceeded it appears therefore impossible either to evolve or make disappear one electric force without

theory of the electric power

1178 The preceding considerations already point to the following conclusions bodies cannot be charged absolutely, but only relatively, and by a *principle* which is the same with that of *induction* All *charge* is sustained by induction All phenomena of *intensity* include the principle of induction All *excitation* is dependent on or directly related to induction All *currents* involve previous intensity and therefore previous induction INDUCTION appears to be the essential function both of the first development and the consequent phenomena of electricity

¶ III *Electrometer and Inductive Apparatus Employed*

1179 Leaving for a time the further consideration of the preceding facts until they can be collated with other results ho 1 the great quest will now cession to impor- tance of t ght to be established is the necessity of doing this so clearly, as to leave no doubt of the results behind

1180 *Electrometer* The measuring instrument I have employed has been the torsion balance electrometer of Coulomb, constructed, generally, according to his directions [1] but with certain variations and additions, which I will briefly describe The lower part was a glass cylinder eight inches in height and eight inches in diameter, the tube for the torsion thread was seventeen inches in length The torsion thread itself was not of metal, but glass, according to the excellent suggestion of the late Dr Ritchie [2] It was twenty inches in length, and of such tenuity that when the shellac lever and attached ball, &c , were connected with it, they made about ten vibrations in a minute It would bear torsion through four revolutions or 1440°, and yet, when released, return accurately to its position, probably it would have borne considerably more than this without injury The repelled ball was of pith, gilt, and was 0 3 of an inch in diameter The horizontal stem or lever supporting it was of shellac, according to Coulomb's direction, the arm carrying the ball being 2 4 inches long and the other only 1 2 inches to this was attached the vane also described by Coulomb, which I found to answer admirably its purpose of quickly destroying vibrations That the inductive action within the electrometer might be uniform in all positions of the repelled ball and in all states of the apparatus, two bands of tinfoil, about an inch wide each, were attached to the inner surface of the glass cylinder, going entirely round it at the distance of 0 4 of an inch from each other, and at such a height that the intermediate clear surface was in the same horizontal plane with the lever and ball These bands were connected with each other and with the earth and, being perfect conductors, always exerted a uniform influence on the electrified balls within, which the glass surface, from its irregularity of condition at different times, I found, did not. For the purpose of keeping the air within the electrometer in a constant state as to dryness a glass dish, of such size as to enter easily within the cylinder, had a layer of fused potash placed within it, and this being covered with a disc of fine wire-gauze to render its inductive action uniform at all parts, was placed within the instrument at the bottom and left there

1181 The movable ball used to take and measure the portion of electricity under examination, and which may be called the *repelling*, or the *carrier*, ball, was of soft alder wood, well and smoothly gilt It was attached to a fine shellac stem, and introduced through a hole into the electrometer according to Coulomb's method the stem was fixed at its upper end in a block or vice, supported on three short feet, and on the surface of the glass cover above was a plate of lead with stops on it, so that when the carrier ball was adjusted in its right position, with the vice above bearing at the same time against these stops, it was perfectly easy to bring away the carrier-ball and restore it to its place again very accurately, without any loss of time

1182 It is quite necessary to attend to certain precautions respecting these balls If of pith alone they are bad, for when very dry, that substance is so imperfect a conductor that it neither receives nor gives a charge freely, and so, after contact with a charged conductor, it is liable to be in an uncertain condition Again, it is difficult to turn pith so smooth as to leave the ball, even when gilt, so free from irregularities of form, as to retain its charge undiminished for a considerable length of time When, therefore, the balls are finally prepared and gilt they should be examined, and being electrified, unless they can hold their charge with very little diminution for a considerable time, and yet be discharged instantly and perfectly by the touch of an uninsulated conductor, they should be dismissed

1 *Mémoires de l Académie 1785 p 570.*
2 *Philosophical Transactions*, 1830.

1183 It is, perhaps, unnecessary to refer to the graduation of the instrument, further than to explain how the observations were made On a circle or ring of paper on the outside of the glass cylinder, fixed so as to cover the internal [illegible]

From one of th [illegible]

upon the upper tinfoil on the opposite side of the cylinder within, and a dot being marked on that point of the surface of the repelled ball nearest to the side of the electrometer, it was easy, by observing the line which this dot made [illegible]

tors on [illegible]

are to be regulated (1181) so that, when the carrier arrangement is placed against them, the centre of the ball may be in the radius of the instrument corresponding to 0° on the lower graduation or that on the side of the electrometer, and at the same level and distance from the centre as the *repelled ball* on the suspended [illegible]

index This state of the instrument was adopted as that which gave the most direct expression of [illegible] and in the form [illegible]

case to be brought, and the whole of the torsion being read off at once on the graduated circle above Under these circumstances the distance of the balls from each other was not merely the same in degree, but their position in the instrument, and in relation to every part of it was actually the same every time that a measurement was made so that all irregularities arising from slight difference of form and action in the instrument and the bodies around were avoided The only difference which could occur in the position of anything within, consisted in the deflexion of the torsion thread from a vertical position, more or less, according to the force of repulsion of the balls but this was so slight as to cause no interfering difference in the symmetry of form within the instrument, and gave no error in the amount of torsion force indicated on the graduation above

1185 Although the constant angular distance of 30° between the centres of the balls was adopted, and found abundantly sensible, for all ordinary purposes, yet the facility of [illegible]

squares of the distances, by calculation

1186 The Coulomb balance electrometer requires experience to be understood but I think it a very valuable instrument in the hands of those who will take pains by practice and at- [illegible]

and fair condition, when the balls were so elec- [illegible]

to it in exactly similar circumstances and in such quantities as should suffice to eliminate any variations they might present The [illegible]

PLATE IX

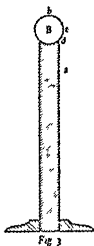


Fig 3

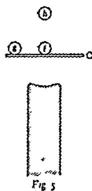


Fig 5

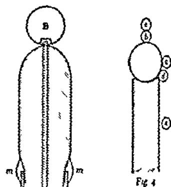


Fig 4

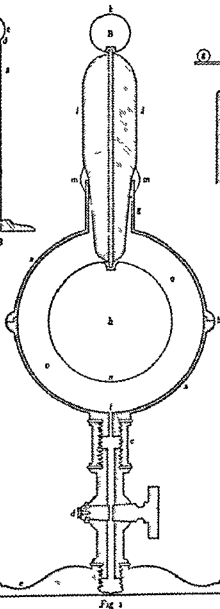


Fig 1

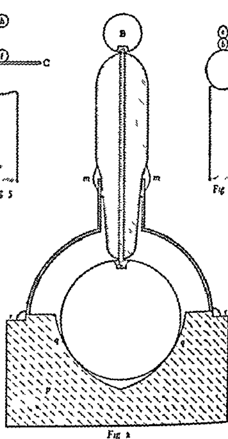


Fig 2

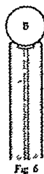


Fig 6

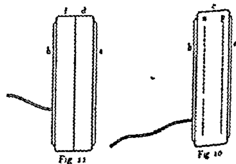


Fig 11 Fig 10

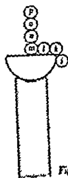


Fig 7

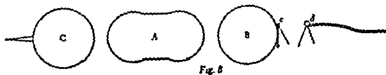


Fig 8



Fig 9

gases might be placed and retained between these surfaces with readiness and certainty, and for any length of time

[illegible]

tion of it is given (Pl IX, *Fig 1*) on a scale of one-half *a*, *a* are the two halves of a brass sphere, with an air-tight joint at *b*, like that of the Magdeburg hemispheres, made perfectly flush and smooth inside so as to present no irregularity, *c* is a connecting piece by which the apparatus is joined to a good stop-cock *d*, which is itself attached either to the metallic foot *e*, or to an air pump The aperture within the hemisphere at *f* is very small *g* is a brass collar

[illegible]

screws on to a brass stem *i*, terminated above by a brass ball B, *l*, *l* is a mass of shellac,

[illegible]

little ordinary resinous cement, more fusible than shellac, applied at *m m* in such a way as to give sufficient strength and render the apparatus air tight there, yet leave as much as possible of the [illegible]

[illegible]

interval *o* may occur during the course of an experiment

1189 It will be unnecessary to give the dimensions of all the parts, since the drawing is to a scale of one-half the inner ball has a diameter of 2 33 inches, and the surrounding sphere an internal diameter of 3 57 inches Hence the width of the intervening space, through which the induction is to take place, is 0 62 of an inch, and the extent of this place or plate, i e the surface of a medium sphere, may be taken as twenty-seven square inches, a quantity considered as sufficiently large for the com- [illegible]

lacquer was applied to them, or to any part of the metal of the apparatus

1190 The attachment and adjustment of the shellac stem was a matter requiring considerable care, especially as, in consequence of its cracking, it had frequently to be renewed The best lac was chosen and applied to the [illegible]

[illegible]

avoided

1191 I had occasion at first to attach the stem to the socket by other means, as a band of paper or a plugging of white silk thread, but these were very inferior to the cement, interfering much with the insulating power of the apparatus

1192 The retentive power of this apparatus [illegible]

[illegible]

was 1 7° per minute, from 200° to 170° it was 1° [illegible]

[illegible]

hereafter (1207, 1250)

1193 When the apparatus loses its insulating power suddenly, it is almost always from a crack near to or within the brass socket These cracks are usually transverse to the stem [illegible] and

[illegible]

ment, may, by the careful application of the heat of a spirit lamp be so far softened and melted as to restore the perfect continuity of the parts but if that does not succeed in replacing things in a good condition, the remedy is a new shellac stem

1194 The apparatus when in order could easily be exhausted of air and filled with any given gas but when that gas was acid or alkaline it could not properly be removed by the air-

with distilled water introduced at the screw-hole and then being heated above 212°, air was blown through to render the interior perfectly dry

1195 The inductive apparatus described is

B, with the connecting wire *i*, constitute the charged conductor, upon the surface of which all the electric force is resident by virtue of induction (1178) Now though the largest portion of this induction is between the ball *h* and the surrounding sphere *a a* yet the wire *i* and the ball B determine a part of the induction from their surfaces towards the external surrounding conductors Still, as all things in that respect remain the same whilst the medium within at *o o*, may be varied any changes exhibited by the whole apparatus will in such cases depend upon the variations made in the

to charge one and measure it, and after dividing the charge with the other, to observe what

could not fail of being developed by such a process

1196 I will wind up this description of the apparatuses, and explain the precautions necessary to their use, by describing the form and order of the experiments made to prove their equality when both contained common air In order to facilitate reference I will distinguish the two by the terms *app* i and *app* ii

1197 The electrometer is first to be adjusted

twentieth of an inch in length between two

torsion index and observe *the force in degrees* required for this purpose this force will in future experiments be called *repulsion of the balls*

1198 One of the inductive apparatus as for instance, app i is now to be charged from the Leyden phial, the latter being in the state it was in when used to charge the balls the carrier ball is to be brought into contact with the top of its upper ball *k* (Pl IX *Fig 1*)

the app i and the measurement repeated the apparatus i and ii are then to be joined so as

app ii charged, measured, divided with app and the force of each again measured and noted If in each case the half charges of app

sulating media or *dielectrics*

1199 But the *precautions* necessary to obtain accurate results are numerous The ap-

this respect, and therefore a sheet of tinfoil, connected with an extensive discharging train (292), is what I have used They must be so

placed also as not to be too near each other, and yet equally exposed to the inductive in-

the apparatus may occur, and so errors be introduced into the results The carrier ball,

1200 As the stem had occasionally to be

was made as to the effect of dampness in the air, one being filled with very dry air, and the other with air from over water Though this produced no change in the result, except an occasional tendency to more rapid dissipation, yet the precaution was always taken when working with gases (1290) to dry them perfectly

1201 It is essential that the interior of the apparatus should be perfectly free from *dust or small loose particles*, for these very rapidly lower the charge and interfere on occasions when

to be well wiped, to remove, in the first instance, the film of wax and adhering matter which is upon it, and afterwards to displace dirt and dust which will gradually attach to it in the course of experiments I have found much to depend upon this precaution, and a

if allowed to remain, it very seriously affects

The best method of removing the charge I have found to be, to cover the finger with a

of dust, whereas in the morning, and in a room which has been left quiet, several experiments can be made in succession without the stem assuming the least degree of charge

1204 Experiments should not be made by candle or lamp light except with much care,

1206 With respect to the balance ... ter, all the precautions that need be mentioned are, that the carrier ball is to be preserved

eter through the hole in the glass plate above,

ing through the steps of the process regularly and quickly, *therefore, after the original charge* has been measured, in app i for instance, i and ii are to be symmetrically joined by their balls B, the carrier touching one of these balls at the same time, it is first to be removed, and then the apparatus separated from each other, app. ii is next quickly to be measured by the carrier, *then app i, lastly, ii is to be discharged*, and the discharged carrier applied to it to ascertain whether any residual effect is present (1205), and app i being discharged is also to be examined in the same manner and for the same purpose.

1208 The following is an example of the division of a charge by the two apparatuses, air being the dielectric in both of them The observations are set down one under the other in the order in which they were taken, the left-hand numbers representing the observations made on app i, and the right-hand numbers those on app ii App i is that which was originally charged and after two measurements the charge was divided with app ii

App i	App ii	
Balls 160°		
	0°	
254°		
250		
divided and instantly taken		
	122	
124		
1		after being discharged
	2	after being discharged

1209 Without endeavouring to allow for the loss which must have been gradually going on during the time of the experiment, let us observe the results of the numbers as they stand As 1° remained in app i in an undischargeable *state, 249° may be taken as the utmost amount* of the transferable or divisible charge, the half of which is 124° 5 As app ii was free of charge in the first instance, and immediately after the division was found with 122°, this amount *at least* may be taken as what it had received On the other hand 124° minus 1°, or 123°, may be *taken* as the half of the transferible charge retained by app i Now these do not differ much from each other, *or from* 124° 5, *the half of the* full amount of transferable charge, and when the gradual loss of charge evident in the *difference* between 254° and 250° of app i is also taken into account, there is every reason to admit the result as showing an equal division of charge, *unattended by any disappearance of power* except that due to dissipation

1210 I will give another result, in which app ii was first charged, and where the residual action of that apparatus was greater than in the former case

App i	App ii	
Balls 150°		
	152°	
	148	
divided and instantly taken		
70°		
	73	
	5	immediately after discharge
0		immediately after discharge

1211 The transferable charge being 148° − 5°, its half is 71° 5, which is not far removed *from 70°, the half charge of i, or from 73°*, the half charge of ii these half charges again making up the sum of 143°, or just the *amount of* the whole transferable charge Considering the errors of experiment, therefore, these results may again be received as showing that the apparatus were equal in inductive capacity, or in *their powers of receiving charges*

1212 The experiments were repeated with *charges of negative electricity with the same* general results

1213 That I might be sure of the sensibility and action of the apparatus, I made such a change in one as ought upon principle to increase its inductive force, i e, I put a metallic lining into the lower hemisphere of app i, *so as to diminish the thickness of the intervening air in that part, from* 0 62 to 0 435 of an inch this lining was *carefully shaped and rounded* so that it should not present a sudden projection within at its edge, but a gradual transition from the reduced interval in the lower part of the sphere to the larger one in the upper

1214 This change immediately caused app i *to produce effects indicating* that it had a greater aptness or capacity for induction than app ii Thus, when a *transferable* charge in app ii of 469° was divided with app i, the former retained a charge of 225°, whilst the latter showed one of 227°, i e the former had lost 244° in communicating 227° to the latter *on* the other hand, when app i had a transferable charge in it of 381° divided by contact with app ii, *it* lost 181° only, whilst it gave to app. ii as many as 194—the sum of the divided *forces being in the first instance less*, and in the second instance *greater* than the original undivided charge *These results are the more* striking, as only one-half of the interior of app i was modified, and they show that the instruments are capable of bringing out differences in inductive force from amongst the

errors of experiment, when these differences are much less than that produced by the alteration made in the present instance

¶ iv *Induction in Curved Lines*

1215 Amongst those results deduced from

portant at present, for, if shown to take place in an unexceptionable manner, I do not see how the old theory of action at a distance and in straight lines can stand, or how the conclusion that ordinary induction is an action of contiguous particles can be resisted

1216 There are many forms of old experiments which might be quoted as favourable to, and consistent with the view I have adopted Such are most cases of electro-chemical decomposition, electrical brushes, auras, sparks, &c , but as these might be considered equivocal evidence inasmuch as they include a current and discharge (though they have long been to me indications of prior molecular action [1230]), I endeavoured to devise such experiments for

insulating media

1218 A cylinder of solid shellac, 0 9 of an inch in diameter and seven inches in length, was fixed upright in a wooden foot (Pl IX, *Fig*

upper half of the stem having been excited *negatively* by friction with warm flannel, a brass ball, B, 1 inch in diameter, was placed on the top, and then the whole arrangement exam

about 360°, and then the carrier being applied to various parts of the ball B, the two were uninsulated whilst in contact or in position, then insulated,[1] separated, and the charge of the carrier examined as to its nature and force Its

at *a*		above 1000°
b it was		149
c		270
d		512
b		130

1219 To comprehend the full force of these results, it must first be understood, that all the

ing contacts, only that due to induction remaining, and this is shown by the charges taken from the ball in this its uninsulated state being always positive, or of the contrary character to the electricity of the shellac In the next place,

tained upon the surface of conductors only by induction (1178), and though some persons may not be prepared as yet to admit this with

be necessary for me to say here

will be found charged with the same kind of electricity as, and even to a *higher degree* (1224) than, if it had been in contact with the summit of B

1221 To suppose, again, that induction acts in some way *through or across* the metal of the ball, is negatived by the simplest considerations, but a fact in proof will be better If instead of the ball B a small disc of metal be

given to the carrier at *f*, though when applied nearer to the edge at *g*, or even *above the middle*

rounding air or *dielectric*, and that in curved lines

1222 I had another arrangement, in which a wire passing downwards through the middle of the shellac cylinder to the earth was connected with the ball B (Pl IX, *Fig 6*) so as to keep it in a constantly uninsulated state This was a very convenient form of apparatus and the results with it were the same as those just described

1223 In another case the ball B was supported by a shellac stem, independently of the excited cylinder of shellac, and at half an inch distance from it, but the effects were the same Then the brass ball of a charged Leyden jar was used in place of the excited shellac to produce induction *but this caused no alteration* of the phenomena Both positive and negative inducing charges were tried with the same general results Finally, the arrangement was inverted in the air for the purpose of removing every possible objection to the conclusions,

still, *p*, the charge taken was smaller in amount, being 98°, and continued to diminish for more elevated positions Here the induction fairly turned a corner Nothing, in fact, can better show both the curved lines or courses of the inductive action, disturbed as they are from their rectilineal form by the shape, position, and condition of the metallic hemisphere, and also a *lateral tension*, so to speak, of these lines on

into a state of polarity and tension, are in mutual relation by their forces in all directions

1225 As another proof that the whole of these actions were inductive I may state a re-

shellac stem, then the inductive force was directed towards it, and could not be found on the top of the hemisphere Removing this matter the lines of force resumed their former direction The experiment affords proofs of the lateral tension of these lines, and supplies a warning to remove such matter in repeating the above investigation

1226 After these results on curved inductive action in air I extended the experiments to other gases, using first carbonic acid and then hydrogen the phenomena were precisely those already described In these experiments I found that if the gases were confined in vessels they required to be very large, for whether of glass

the carrier ball in the positions *k*, *l*, *m*, *n*, *o*, *p* (Pl IX, *Fig 7*) A very good mode of making the experiment is to let large currents of the gases ascend or descend through the air, and carry on the experiments in these currents

and being then placed upon the top of the brass hemisphere (*Fig* 7), observations were made with the carrier ball as before (1224) The results were the same, and the circumstance of some of the positions being within the fluid and some without, made no sensible difference

1228 Lastly, I used a few solid dielectrics

9) arranged on the excited lac as in former cases, and observations were made at *n*, *o*, *p*, and *q* Great care was required in these experiments to free the sulphur or other solid substance from any charge it might previously

moved and again examined, to ascertain that it had received no charge, but had acted really as a *dielectric* With all these precautions the results were the same and it is thus very satis-

This effect is consistent with what will here-

sulated, will *give signs of electricity*, *opposite* in its nature to that of A, and therefore caused by induction, although the influencing and influenced bodies cannot be joined by a right line passing through the air Or if the electrom-

have ventured to put forth, I cannot see how the preceding results can be avoided The effects are clearly inductive effects produced by electricity, not in currents but in its statical state, and this induction is exerted in lines of force which, though in many experiments they may be straight, are here curved more or less according to circumstances I use the term *line of inductive force* merely as a temporary conventional mode of expressing the direction of the power in cases of induction, and in the experiments with the hemisphere (1224), it is curious to see how, when certain lines have terminated on the under surface and edge of the metal, those which were before lateral to

[1] *Encyclopædia Britannica* [7th edition] Vol. VI

magnetic needles, or to the condition of the particles considered as forming the whole of a straight or a curved magnet So that in whatever way I view it and with great suspicion of *the influence of favourite notions over myself*, I cannot perceive how the ordinary theory applied to explain induction can be a correct representation of that great natural principle of electrical action

1232 *I have had occasion in describing the* precautions necessary in the use of the inductive apparatus, to refer to one founded on induction in curved lines (1203), and after the experiments already described, it will easily be *seen how* great an influence the shellac stem may exert upon the charge of the carrier ball when applied to the apparatus (1218), unless that precaution be attended to

1233 I think it expedient, next in the course of *these experimental researches*, to describe some effects due to *conduction*, obtained with such bodies as glass, lac, sulphur, &c , which had not been anticipated Being understood, they will make us acquainted with certain *precautions necessary in investigating the great* question of specific inductive capacity

1234 One of the inductive apparatus already described (1187, &c) had a hemispherical cup of shellac introduced which being in the interval *between the inner ball* and *the lower hemisphere*, nearly occupied the space there consequently when the apparatus was charged, the lac was the dielectric or insulating medium through which the induction took place in that *part When this apparatus was first charged* with electricity (1198) up to a certain intensity, as 400°, measured by the COULOMB's electrometer (1180), it sank much faster from that degree than if it had been previously charged *to a higher point*, and had gradually fallen to 400°, or than it would do if the charge were, by a second application, raised up again to 400°, all other things remaining the same Again if after having been charged for some time, as fifteen or twenty minutes, it was suddenly and perfectly discharged, even the stem having all electricity removed from it (1203), then the apparatus being left to itself, would gradually recover a charge, which in nine or ten minutes would rise up to 50° or 60°, and in one instance to 80°.

1235. The electricity, which in these cases returned from an apparently latent to a sensible state, was always of the same kind as that which had been given by the charge The return took place at both the inducing surfaces, for if after the perfect discharge of the apparatus the whole was insulated, as the inner ball resumed a positive state the outer sphere acquired a negative condition.

1236 This effect was at once distinguished from that produced by *the excited stem acting* in curved lines of induction (1203, 1232), by the circumstance that all the returned electricity could be perfectly and instantly discharged It appeared to depend upon the shellac within, *and to be, in some way, due to electricity* evolved from it in consequence of a previous condition into which it had been brought by the charge of the metallic coatings or balls

1237 To examine this state more accurately, the apparatus, with *the hemispherical cup of* shellac in it, was charged for about forty five minutes to above 600° with positive electricity at the balls *h* and B (*Fig 104*) above and within It was then discharged, *opened, the shellac taken out, and its state examined this* was done by bringing the carrier ball near the shellac, uninsulating it, insulating it, and then observing what charge it had acquired As it would be a charge by induction, the state of *the ball would indicate the opposite state of* electricity in that surface of the shellac which had produced it At first the lac appeared quite free from any charge, but gradually its two surfaces assumed opposite states of electricity, *the concave surface, which had been next* the inner and positive ball, assuming a positive state, and the convex surface, which had been in contact with the negative coating, acquiring a negative state these states gradually *increased in intensity for some* time

1238 As the return action was evidently greatest instantly after the discharge, I again put the apparatus together, and charged it for fifteen minutes as before, the inner ball positively I then discharged it instantly removing the upper hemisphere with the interior ball, and, leaving the shellac cup in the lower uninsulated hemisphere, examined its inner surface by the carrier ball as before (1237) In this way I found the surface of the shellac actually *negative*, or in the reverse state to the ball which had been in it, this state quickly disappeared and was succeeded by a positive condition, gradually increasing in intensity *for some time*, in the same manner as before The first negative condition of the surface opposite *the positive* charging ball is a natural consequence of the state of things, the charging ball being in contact with the shellac only *in a few points* It does not interfere with the general result and peculiar state now under consideration, except

that it assists in illustrating in a very marked manner the ultimate assumption by the surfaces of the shellac of an electrified condition similar to that of the metallic surfaces opposed to or against them

1239 *Glass* was then examined with respect to its power of assuming this peculiar state I had a thick flint-glass hemispherical cup formed which would fit easily into the space *o* of the lower hemisphere (1188 1189) it had been heated and varnished with a solution of shellac in alcohol for the purpose of destroying the conducting power of the vitreous surface (1254) Being then well warmed and experimented with I found it could also assume the *same state* but not apparently to the same degree the return action amounting in different cases to quantities from 6° to 18°

1240 *Sperm aceti* experimented with in the same manner gave striking results When the original charge had been sustained for fifteen or twenty minutes at about 500° the return charge was equal to 95° or 100° and was about fourteen minutes arriving at the maximum effect A charge continued for not more than two or three seconds was here succeeded by a return charge of 50° or 60° The observations

der consideration

1241 *Sulphur* I was anxious to obtain the amount of effect with this substance first because it is an excellent insulator and in that respect would illustrate the relation of the ef

t on for the investigation of the question of specific inductive capacity (1277)

most perfect insulators gave very little of this return charge

1243 I tried the same experiment having air

After a con

1244 I sought to produce something like this state with one electric power and without induction for upon the theory of an electric flu d or fluids that did not seem impossible and then I should have obtained an absolute charge (1169 1177) or something equivalent to it In this I could not succeed I excited the outside of a cylinder of shellac very highly for some time and then quickly discharging it (1203) waited and watched whether any re-

1245 Although inclined at first to refer these effects to a peculiar masked condition of a certain portion of the forces I think I have since correctly traced them to known principles of

surfaces of c, and consequently to the conductors a and b, and constitutes the recharge observed

1246 The following is the experiment on which I rest for the truth of this view Two plates of spermaceti, d and f (Pl IX, *Fig 11*), were put together to form the dielectric, a and b being the metallic coatings of this compound plate, as before The system was charged, then discharged, insulated, examined, and found to give no indications of electricity to the carrier ball The plates d and f were then separated from each other, and instantly a with d was found in a positive state, and b with f in a negative state, nearly all the electricity being in

plates from each other s inductive influence,

the contiguous particles of matter only, then each half plate, d and f, should have shown positive force on one surface and negative on the other

1247 Thus it would appear that the best solid insulators, such as shellac, glass, and sulphur, have conductive properties to such an extent, that electricity can penetrate them bod-

instance whilst the original charge is sustained, less time would be required for the assumption of the particular state, and more electricity would re-appear as return charge

1248 The condition of *time required for this* penetration of the charge is important, both as respects the general relation of the cases to conduction, and also the removal of an objection that might otherwise properly be raised to

diffusion of electricity over the uncoated por-

described A plate of shellac six inches square, and half an inch thick, or a similar plate of spermaceti an inch thick, being coated on the sides with tinfoil as a Leyden arrangement, will show this effect exceedingly well

1250 The peculiar condition of dielectrics which has now been described, is evidently capable of producing an effect interfering with the results and conclusions drawn from the use

tension than the other For suppose app charged, and app used to divide with it though both may actually lose alike, yet app which has been diminished one-half, will be

interference by performing the whole process

peculiar state could be produced, and I have assumed that as about three minutes pass between the first charge of app and the division, and three minutes between the division and discharge, when the force of the non transferable electricity is measured, the contrary tendencies for those periods would keep that apparatus in a moderately steady and uniform condition for the latter portion of time

1251 *The particular action* described occurs in the shellac of the stems, as well as in the *dielectric* used within the apparatuses It therefore constitutes a cause by which the outside of the stems may in some operations become

charged with electricity, independent of the *action of dust or carrying particles* (1203)*

¶ v. *On Specific Induction, or Specific Inductive Capacity*

1252 *I now proceed to examine the great* question of specific inductive capacity, i e, whether *different dielectric bodies actually do* possess any influence over the degree of induction which *takes place through them. If any* such difference should exist, it appeared to me not only of high *importance in the further* comprehension of the laws and results of induction, but an additional and very powerful argument for the theory I have ventured to put forth, that the whole depends upon a molecular action, in contradistinction to one at sensible distances

The question may be stated thus suppose A *an electrified plate of metal suspended in the* air, and B and C two exactly similar plates, placed parallel to and on each side of A at equal distances and uninsulated, A will then induce equally towards B and C If in this position of the plates some other dielectric than air, as shellac, be introduced between A and C, will the induction between them remain the same? Will the relation of C and B to A be unaltered, *notwithstanding the difference of the* dielectrics interposed between them?[1]

1253 *As far as I recollect, it is assumed that* no change will occur under such variation of circumstances, and that *the relations of B and* C to A depend entirely upon their distance I only remember one experimental illustration of the question, and that is by Coulomb[2] in which he shows that a wire surrounded by shellac took exactly the same quantity of electricity from a charged body as the same wire in air The experiment offered to me no proof of the truth of the supposition for it is not the mere films of dielectric substances surrounding the charged body which have to be examined and compared, but *the whole mass between* that body and the surrounding conductors at *which the induction terminates* Charge depends upon induction (1171, 1178), and if induction *is related* to the particles of the surrounding dielectric, then it is related to *all* the particles of that dielectric inclosed by the surrounding conductors, and not merely to the few situated next to the charged body Whether the difference I sought for existed or not, I soon found reason to doubt the conclusion that might be drawn from Coulomb's result, and therefore had the apparatus made, which, with its use, has been already described (1187, &c), and which appears to me well suited for the investigation of the question

1254 *Glass,* and many bodies which might at first be considered as very fit to test the *principle, proved exceedingly unfit for that* purpose Glass, principally in consequence of *the alkali it contains, however well warmed* and dried it may be, has a certain degree of conducting power upon its *surface,* dependent upon the moisture of the atmosphere, which renders it unfit for a test experiment Resin, wax, naphtha, oil of turpentine, and many other substances were in turn rejected, because of a slight degree of conducting power possessed by *them, and ultimately shellac and sulphur* were chosen, after many experiments, as the dielectrics best fitted *for the* investigation No difficulty can arise in perceiving how the possession of a feeble degree of conducting power tends to make a body produce effects, which would seem to indicate that it had a greater capability of allowing induction through it than another body perfect in its insulation This *source of error has been that which I have* found most difficult to obviate in the proving *experiments*

1255 *Induction through shellac* As a preparatory experiment, I first ascertained generally that when a part of the surface of a thick plate of shellac was excited or charged, there was no sensible difference in the character of the induction sustained by that charged part, whether exerted through the air in the one direction, or through the shellac of the plate in the other, provided the second surface of the *plate had not, by contact with conductors, the* action of dust, or any other means, become *charged* (1203) *Its solid condition* enabled it to retain the excited particles in a permanent position, but that appeared to be all, for these particles acted just as freely through the shellac on one side as through the air on the other. The same general experiment was made by attaching a disc of tinfoil to one side of the shellac plate, and *electrifying* it, and the results were the same Scarcely any other solid substance *than shellac and sulphur, and no liquid* substance that I have tried, will bear this examination Glass in its ordinary state utterly fails, yet it was essentially necessary to obtain this—

[1] Refer for the practical illustration of this statement to the *supplementary note* commencing 1307, &c—*Dec* 1838

[2] *Mémoires de l Académie*, 1787, pp 452, 453

prior degree of perfection in the dielectric used, before any *further progress* could be made in the principal investigation

1256 *Shellac and air were compared in the* first place For this purpose a thick hemispherical cup of shellac was introduced into the lower hemisphere of one of the inductive apparatus (1187, &c.), so as nearly to fill the lower half of the space *o*, *o* (Pl IX, *Fig. 1*) between it and the inner ball, and then charges were divided in the manner already described (1198, 1207), each apparatus being used in turn to receive *the first charge before its division by the other As the apparatuses were known to have equal inductive power when air was in both (1209, 1211)*, any differences resulting from the *introduction* of the shellac would show a peculiar action in it, and if unequivocally referable to a specific inductive influence, would establish the point sought to be sustained I have already referred to the precautions necessary in making the experiments (1199, &c), and with respect to the error which might be introduced by the assumption of the peculiar state, it was guarded *against, as far as possible, in the first place, by operating quickly (1248)* and *afterwards*, by using that dielectric as glass or sulphur, which assumed the peculiar state most slowly, and in the least degree (1239, 1241)

1257 The shellac hemisphere was put into app i, and app ii left filled with air The results of an experiment in which the charge through air was *divided* and reduced by the *shellac app were as follows*

App i. Lac	App ii Air	
	Balls 255°	
0°		
	304°	
	297	
Charge divided		
113		
	121	
0		after being discharged
	7	after being discharged

1258. Here 297°, minus 7°, or 290°, may be taken as the divisible charge of app. ii (the 7° being fixed stem action [1203, 1232]), of which 145° is the half The lac app i gave 113° as the power or tension it had acquired after division, and the air app ii gave 121°, minus 7°, or 114°, as the force it possessed *from* what it *retained of the divisible charge of 290°. These two numbers should* evidently be alike, and they are very nearly so, indeed far within the errors of experiment and observation But these numbers differ very much from 145°, or the force which the half charge would have had if app i had contained air instead of shellac and it appears that whilst in the division the induction *through the air* has lost 176° of *force*, that through the *lac* has only gained 113°.

1259 If this *difference* be assumed as depending entirely on the greater *facility* possessed by shellac of allowing or causing inductive action through its substance than that possessed by air, then this capacity for electric induction would be inversely as the respective loss and gain indicated above and assuming the capacity of the air apparatus as 1, that of the shellac apparatus would be $\frac{176}{113}$ or 1.55

1260 This extraordinary difference was so unexpected in its amount, as to excite the greatest *suspicion of* the *general accuracy* of the experiment, though the perfect discharge of app i after the division, showed that the 113° had been taken and given up readily It was evident that if it really existed it ought to produce corresponding effects in the reverse order and that when induction through shellac was converted into induction through air, *the force* or tension of the whole *ought to be increased* The app i was *therefore* charged *in* the first place and *its force divided with* app ii The following were the results

App i Lac	App ii. Air	
	0°	
215°		
204		
Charge divided		
	118	
118		
	0	*after being* discharged
0		after being discharged

1261 Here 204° must be the utmost of the divisible charge The app i and app ii present 118° as their respective forces both now much *above* the half of the first force, or 102°, whereas in the former case they were below *it The lac* app i has lost only 86°, yet it has *given to the air app ii 118°, so that the lac still appears much to surpass the air*, the capacity of the lac app i to the air app ii being as 1.37 to 1

1262 The difference of 1.55 and 1.37 as the expression of the capacity for the induction *of* shellac seems considerable, but is *in reality very admissible under the circumstances for both are in error in contrary directions Thus in the last experiment the charge fell from* 215° to 204° by the *joint effects* of dissipation and absorption (1192, 1250), during the time which elapsed in the electrometer operations between the applications of the carrier ball required to give those two results Nearly an equal *time must have* elapsed between the application *of the carrier*

which gave the 204° result and the division of the charge between the two apparatus and as the fall in force progressively decreases in

charge to 80° instead of 86° and then the expression of specific capacity for it is increased, and instead of 1 37, is 1 47 times that of air

1263 Applying the same correction to the former experiment in which air was *first* charged, the result is of the *contrary* kind No shellac hemisphere was then in the apparatus and therefore the loss would be principally from dissipation, and not from absorption hence it would be near-

ed only 113° to the shellac, and the relative specific capacity of the latter would appear to be 1 50, which is very little indeed removed from 1 47, the expression given by the second experiment when corrected in the same way

1264 The shellac was then removed from app i and put into app ii and the experiments of division again made I give the results because I think the importance of the point justifies and even requires them

App i Air	App ii Lac
Balls 200°	
	0°
286°	
283	
Charge divided	
	110
100	
	0 25 after discharge
Trace	after discharge

as 1 to 1 58 If the divided charge be correct

charge divided thus

App i Air	App ii Lac
0°	
	256°
	251
Charge divided	
146	
	149
a little	after discharge
	a little after discharge

duction, it proved the growing necessity of a more close and rigid examination of the whole question

1267 The shellac was of the best quality, and had been carefully selected and cleaned,

of the conductors in that apparatus were nearer together than in the one with air only I pre-

tus showed its former superiority, and whether it or the air apparatus was charged first, the capacity of the lac apparatus to the air apparatus was by the experimental results as 1 45 to 1.

1269 From all the experiments I have made, and their constant results, I cannot resist the conclusion that shellac does exhibit a case of *specific inductive capacity* I have tried to check the trials in every way, and if not remove, at least estimate, every source of error That the final result is not due to common conduction is

particles, by which they could acquire a polarized condition as conductors, is shown by the effects of the shellac purified by alcohol, and, *that it is not due to any influence of the charged*

cerned in the phenomena, that instantaneous effect occurring in these cases, as in all others of ordinary induction, by charged conductors The latter argument is the more striking in the

and yet is charged far above the *mean*

occupies one-half of the space *o*, *o*, of the apparatus containing it, through which the in-

1271 *Glass* I next worked with glass as the dielectric It involved the possibility of con-

this it does not assume the charged state (1239) so readily, or to such an extent, as shellac

1272 A thin hemispherical cup of glass being made hot was covered with a coat of shellac dissolved in alcohol, and after being dried for many hours in a hot place was put into the apparatus and experimented with It exhibited

surfaces It was covered with a film of shellac

surpassed air in its power of favouring induction through it The two best results as re-

out correction The average of nine results four with the glass apparatus first charged and five with the air apparatus first charged, gave 1 38 as the power of the glass apparatus, 1.22 and 1 46 being the minimum and maximum numbers with all the errors of experiment upon them In all the experiments the glass apparatus took up its inductive charge instantly, and lost it as readily (1269), and during the short time of each experiment, acquired the peculiar *state in a small degree only*, so that the influ-

1275 *Sulphur* The same hemisphere of this substance was used in app n as was formerly

referred to (1242). The experiments were well made, i e the sulphur itself was free from charge both before and after each experiment, and no action from the stem appeared (1203, 1232), so that no correction was required on that account The following are the results when the air apparatus was first charged and divided

App i Air	App ii Sulphur
Balls 280°	
0°	
	0°
438	
434	
Charge divided	
	162
164	
	160
162	
	0 after discharge
0 after discharge	

Here app i retained 164°, having lost 270° in communicating 162° to app ii and the capacity of the air apparatus is to that of the sulphur apparatus as 1 to 1 66

1276 Then the sulphur apparatus was charged first, thus

	0°
0°	
	395
	388
Charge divided	
237	
	238
0 after discharge	
	0 after discharge

Here app ii retained 238°, and gave up 150° in communicating a charge of 237° to app i and the capacity of the air apparatus is to that of the sulphur apparatus as 1 to 1.58 These results are very near to each other, and we may take the mean 1 62 as representing the specific inductive capacity of the sulphur apparatus in which case the specific inductive capacity of sulphur itself as compared to air=1 (1270) will be about or above 2.24

1277 This result with sulphur I consider as one of the most unexceptionable The substance when fused was perfectly clear, pellucid and free from particles of dirt (1267), so that no interference of small conducting bodies confused the result The substance when solid is an excellent insulator, and by experiment was found to take up, with great slowness, that state (1241, 1242) which alone seemed likely to disturb the conclusion The experiments themselves, also, were free from any need of correction Yet notwithstanding these circumstances, so favourable to the exclusion of error, the result is a higher specific inductive capacity for sulphur than for any other body as yet tried, and though this may in part be due to the sulphur being in a better shape, i e, filling up more completely the space *o*, *o*, (Pl X, *Fig 1*) than the cups of shellac and glass, still I feel satisfied that the experiments altogether fully prove the existence of a difference between dielectrics as to their power of favouring an inductive action through them, which difference may, for the present, be expressed by the term *specific inductive capacity*

1278 Having thus established the point in the most favourable cases that I could anticipate I proceeded to examine other bodies amongst solids, liquids, and gases These results I shall give with all convenient brevity

1279 *Spermaceti* A good hemisphere of spermaceti being tried as to conducting power whilst its two surfaces were still in contact with the tinfoil moulds used in forming it was found to conduct sensibly even whilst warm On removing it from the moulds and using it in one of the apparatuses it gave results indicating a specific inductive capacity between 1 3 and 1 6 for the apparatus containing it But as the only mode of operation was to charge the air apparatus, and then after a quick contact with the spermaceti apparatus, ascertain what was left in the former (1281), no great confidence can be placed in the results They are not in opposition to the general conclusion but can not be brought forward as argument in favour of it

1280 I endeavoured to find some liquids which would insulate well, and could be obtained in sufficient quantity for these experiments Oil of turpentine, native naphtha rectified, and the condensed oil gas fluid appeared by common experiments to promise best as to insulation Being left in contact with fused carbonate of potassa, chloride of lime, and quick lime for some days and then filtered, they were found much injured in insulating power, but after distillation acquired their best state, though even then they proved to be conductors when extensive metallic contact was made with them.

1281 *Oil of turpentine rectified* I filled the lower half of app. i with the fluid and as it would not hold a charge sufficiently to enable me first to measure and then divide it, I charged app ii containing air, and dividing its charge

with app I by a quick contact, measured that remaining in app. II for, theoretically, if a quick contact would divide up to equal tension between the two apparatuses, yet without sensible loss from the conducting power of app I, and app II were left charged to a degree of tension above half the original charge, it would indicate that oil of turpentine had less specific inductive capacity than air, or, if left charged below that mean state of tension, it would imply that the fluid had the greater inductive capacity In an experiment of this kind, app II gave as its charge 390° before division with app I, and 175° afterwards, which is less than the half of 390° Again, being at 175° before division, it was 79° after which is also less than half the divided charge Being at 79°, it was a third time divided, and then fell to 36°, less than the half of 79° Such are the best results I could obtain, they are not inconsistent with the belief that oil of turpentine has a greater specific capacity than air, but they do not prove the fact, since the disappearance of more than half the charge may be due to the conducting power merely of the fluid

1282 *Naphtha* This liquid gave results similar in their nature and direction to those with oil of turpentine.

1283 A most interesting class of substances, *in relation to specific inductive capacity*, now came under review, namely, the gases or aeriform bodies These are so peculiarly constituted, and are bound together by so many striking physical and chemical relations, that I expected some remarkable results from them air in various states was selected for the first experiments

1284 *Air, rare and dense* Some experiments of division (1208) seemed to show that dense and rare air were alike in the property under examination A simple and better process was to attach one of the apparatuses to an air-pump, to charge it, and then examine the tension of the charge when the air within was more or less rarefied Under these circumstances it was found, that commencing with a certain charge, that charge did not change in its tension or force as the air was rarefied, until the rarefaction was such that *discharge* across the space *o*, *o* (Pl IX, *Fig 1*) occurred This discharge was proportionate to the rarefaction, but having taken place, and lowered the tension to a certain degree, that degree was not at all affected by restoring the pressure and density of the air to their first quantities

	Inches of Mercury		
Thus at a pressure of	30	the charge was	88°
Again	30	the charge was	88
Again	30	the charge was	87
Reduced to	14	the charge was	87
Raised again to	30	the charge was	86
Being now reduced to	3 4	the charge fell to	81
Raised again to	30	the charge was still	81

1285 The charges were low in these experiments, first that they might not pass off at low pressure, and next that little loss by dissipation might occur I now reduced them still lower, that I might rarefy further, and for this purpose in the following experiment used a measuring interval in the electrometer of only 15° (1185) The pressure of air within the apparatus being reduced to 1 9 inches of mercury, the charge was found to be 29°, then letting in air till the pressure was 30 inches, the charge was still 29°

1286 These experiments were repeated with pure oxygen with the same consequences

1287 This result of *no variation* in the electric tension being produced by variation in the density or pressure of the air, agrees perfectly with those obtained by Mr Harris,[1] and described in his beautiful and important investigations contained in the *Philosophical Transactions*, namely that induction is the same in rare and dense air, and that the divergence of an electrometer under such variations of the air continues the same, provided no electricity pass away from it The effect is one entirely independent of that power which dense air has of causing a higher charge to be *retained* upon the surface of conductors in it than can be retained by the same conductors in rare air, a point I propose considering hereafter.

1288 I then compared *hot and cold air* together, by raising the temperature of one of the inductive apparatus as high as it could be without injury, and then dividing charges between it and the other apparatus containing cold air The temperatures were about 50° and 200° Still the power or capacity appeared to be unchanged, and when I endeavoured to vary the experiment, by charging a cold apparatus and then warming it by a spirit lamp, I could obtain no proof that the inductive capacity underwent any alteration

1289 I compared *damp and dry air* together, but could find *no difference* in the results

1290 *Gases* A very long series of experiments

[1] *Philosophical Transactions* 1834 pp 223, 224, 237, 244

was then undertaken for the purpose of comparing *different gases* one with another They were all found to insulate well, except such as acted on the shellac of the supporting stem, these were chlorine, ammonia, and muriatic acid They were all dried by appropriate means before being introduced into the apparatus It would have been sufficient to have compared each with air, but, in consequence of the strik-

variation of density or pressure produced any effect), I was induced to compare them, experimentally, two and two in various ways,

presented

1291 The experiments were made upon the following pairs of gases

1 Nitrogen and	Oxygen
2 Oxygen	Air
3 Hydrogen	Air
4 Muriatic acid gas	Air
5 Oxygen	Hydrogen
6 Oxygen	Carbonic acid
7 Oxygen	Olefiant gas
8 Oxygen	Nitrous gas
9 Oxygen	Sulphurous acid
10 Oxygen	Ammonia
11 Hydrogen	Carbonic acid
12 Hydrogen	Olefiant gas
13 Hydrogen	Sulphurous acid
14 Hydrogen	Fluo-silicic acid
15 Hydrogen	Ammonia
16 Hydrogen	Arseniuretted hydrogen
17 Hydrogen	*Sulphuretted hydrogen*
18 Nitrogen	Olefiant gas
19 Nitrogen	Nitrous gas
20 Nitrogen	Nitrous oxide
21 Nitrogen	Ammonia
22 Carbonic oxide	Carbonic acid
23 Carbonic oxide	Olefiant gas
24 Nitrous oxide	Nitrous gas
25 Ammonia	Sulphurous acid

1292 Notwithstanding the striking contrasts of all kinds which these gases present of property, of density, whether simple or compound, ... (665), of high or low pres-

more important, and adds one to the many striking relations which hold between bodies having the gaseous condition and form Another equally important electrical relation, which will be examined in the next paper,[1] is that which the different gases have to each other at the *same pressure* of causing the retention of the *same or different degrees of charge* upon conductors in them These two results appear to bear importantly upon the subject of electrochemical excitation and decomposition, for as *all* these phenomena, different as they seem to be, must depend upon the electrical forces of the particles of matter, the very distance at which they seem to stand from each other will do much, if properly considered, to illustrate the principle by which they are held in one common bond, and subject, as they must be, to one common law

1293 It is just possible that the gases may

dielectrics

1294 The insulation was good in all the experiments recorded, except Nos 10, 15, 21, and 25, being those in which ammonia was

¶vi *General Results as to Induction*

1295 Thus *induction* appears to be essentially an action of contiguous particles, through the intermediation of which the electric force, originating or appearing at a certain place, is propagated to or sustained at a ...

[1] See in relation to this point 1382

pearing there as a *force* of the same kind exactly equal in amount, but opposite in its direction and tendencies (1164) Induction requires no sensible thickness in the conductors which may be used to limit its extent, an uninsulated leaf of gold may be made very highly positive on one surface, and as highly negative on the other, without the least interference of the two states whilst the inductions continue Nor is it affected by the nature of the limiting *conductors, provided time be allowed, in the case of those which conduct slowly, for them to assume their final state* (1170).

1296 But with regard to the *dielectrics* or insulating media, matters are very different (1167). Their thickness has an immediate and important influence on the degree of induction As to their quality, though all gases and vapours are alike, whatever their state; yet amongst solid bodies, and between them and gases, there are differences which prove the existence of *specific inductive capacities*, these differences being in some cases very great

1297 The direct inductive force, which may be conceived to be exerted in lines between the *two limiting and charged conducting surfaces, is accompanied by a lateral or transverse force* equivalent to a dilatation or repulsion of these representative lines (1224), or the attractive force which exists amongst the particles of the dielectric in the direction of the induction is accompanied by a repulsive or a diverging force in the transverse direction (1304)

1298 Induction appears to consist in a certain polarized state of the particles, into which they are thrown by the electrified body sustaining the action, the particles assuming positive and negative points or parts, which are symmetrically arranged with respect to each other and the inducting surfaces or particles [1] The state must be a forced one, *for it is originated* and sustained only by force, and sinks to the *normal or quiescent state* when that *force is removed It can be continued only in insulators by the same portion of electricity, because they only can retain this state of the particles* (1304).

1299 The principle of induction is of the utmost generality in electric action It constitutes charge in every ordinary case, and probably in every case, it appears to be the cause of all excitement, and to precede every current. The degree to which the particles are affected in this their forced state, before discharge of one kind or another supervenes, appears to constitute what we call *intensity*

1300 When a Leyden jar is *charged*, the particles of the glass are forced into this polarized and constrained condition by the electricity of the charging apparatus. *Discharge* is the *return of these particles to their natural state from their state of tension*, whenever the two *electric forces are allowed to be disposed of in some other direction*

1301 *All* charge of conductors is on their surface, because being essentially inductive, it is there *only* that the medium capable of sustaining the necessary inductive state begins *If* the conductors are hollow and contain air or any other dielectric, still no *charge* can appear upon that internal surface, because *the dielectric* there cannot assume the polarized state throughout, in consequence of the opposing actions in different directions.

1302 The known *influence of form* is perfectly *consistent with the corpuscular view of induction set forth* An electrified cylinder is *more affected by the influence of the surrounding conductors* (which complete the *condition* of charge) at the ends than at the *middle*, because the ends are exposed to a *greater sum of* inductive forces than the middle, and *a point* is brought to a higher condition than a *ball* because by relation to the conductors around, more inductive force terminates on its *surface* than on an equal surface of the ball with which it is compared Here too, especially, can be perceived the influence of the lateral or transverse force (1297), which, being a power of the nature of or equivalent to repulsion, causes such a disposition of the lines of inductive force in their course across the dielectric, that they must accumulate upon the point, the end of the cylinder, *or any projecting part*

1303 The *influence of distance* is also in harmony with the same view There is perhaps no *distance so great that* induction cannot take *place through it* [2] *but* [illegible]

[illegible]

[illegible] And as it is as-

[1] *The theory of induction which I am stating does not pretend to decide whether electricity be a fluid or fluids or a mere power or condition of recognized matter That is a question which I may be induced to consider in the next or following series of these researches.*

[2] I have traced it experimentally from a ball placed in the middle of the *large cube formerly described* (1173) to the sides of the cube six feet distant and also from the same ball placed in the *middle of our* large lecture-room to the walls of the room at twenty-six *feet distance the charge sustained* upon the ball in these cases being solely due to induction through these distances.

sumed by the theory that the particles of the die-

tive force and *curved lines* of force (1231, 1297, 1298, 1302) in a general sense only, just as we speak of the lines of magnetic force The lines are imaginary, and the force in any part of them is of course the resultant of compound forces, every molecule being related to every other molecule in *all* directions by the tension and reaction of those which are contiguous The transverse force is merely this relation considered in a direction oblique to the lines of inductive force, and at present I mean no more than that by the phrase With respect to the term *polarity* also, I mean at present only a disposition of force by which the same mole-

produces variety of electrical relation[1] All I am anxious about at present is, that a more

render the explanation of electrical phenomena day by day more and more definite

1305 As a test of the probable accuracy of

To my feeling it is insufficient in accounting for the retention of electricity upon the surface of conductors by the pressure of the air, an effect which I hope to show is simple and consistent according to the present view,[3] and it does not touch voltaic electricity, or in any way associate it and what is called ordinary electricity under one common principle

their exactness, but I am happy in perceiving no collision at present between them and the views I have taken

1306 Finally I beg to say that I put forth my particular view with doubt and fear, lest it should not bear the test of general examination for unless true it will only embarrass the

ent in kind urged me to write the present paper I as yet see no inconsistency between it and nature but, on the contrary, think I perceive much new light thrown by it on her operations and my next papers will be devoted to a review of the phenomena of conduc-

Royal Institution, November 16, 1837

Supplementary Note to Experimental Researches in Electricity Eleventh Series
RECEIVED MARCH 29, 1838

1307 I have recently put into an experimental form that general statement of the ques-

circular brass plates, about five inches in diameter, were mounted side by side upon insu-

[1] See now 1685 &c —*Dec* 1838
[2] *Mémoires de l Institut* 1811 Vol XII the first page 1 and the second paging 163

[3] Refer to 1377 1378 1379 1398
[4] *Philosophical Transactions* 183

any required distance. Two gold leaves were suspended in a glass jar from insulated wires, one of the outer plates B was connected with one of the gold leaves, and the other outer plate with the other leaf The outer plates B and C were adjusted at *the distance of an* inch and a quarter from the middle plate A, and the gold leaves were fixed at two inches apart, A was then slightly charged with electricity, and the plates B and C, with their gold leaves, thrown out of insulation *at the same time*, and then left insulated In this state of things A was charged positive inductrically, and B and C negative inducteously, the same dielectric, air, being in the two intervals, and the gold leaves hanging, of course, parallel to each other in a relatively unelectrified state

1308 A plate of shellac three quarters of an inch in thickness, and four inches square, suspended by clean white silk thread, was very carefully deprived of all charge (1203) (so that it produced no effect on the gold leaves if A were uncharged) and then introduced between plates A and B, the electric relation of the three plates was immediately altered and the gold leaves attracted ... the ...

... , and the shellac examined by a delicate Coulomb electrometer was still without charge.

1309 As A was positive, B and C were of course negative, but as the specific inductive capacity of shellac is about twice that of air *(1270), it was expected that when the lac was* introduced between A and B, A would induce more towards B than towards C, that therefore B would become more negative than before towards A, and consequently, because of its insulated condition be positive externally, as at its back or at the gold leaves, whilst C would be less negative towards A, and therefore negative outwards or at the gold leaves This was found to be the case, for on whichever side of A the shellac was introduced the external plate at that side was positive, and the external plate on the other side negative towards each other, and also to uninsulated external bodies

1310 On employing ...

... these effects of specific inductive capacity can be exalted in various ways, and it is this capability which makes the great value of the apparatus Thus I introduced the shellac between A and B, and then for a moment connected B and C, uninsulated them, and finally left them in the insulated state the gold leaves were of course hanging parallel to each other On removing the shellac the gold leaves attracted each other, on introducing the shellac between A and C this attraction was *increased* (as had been anticipated from theory), and the leaves came together, though not more than four inches long, and hanging three inches apart

1312 By simply bringing the gold leaves nearer to each other I was able to show the difference of specific inductive capacity when only thin plates of shellac were used, the rest of the dielectric space being filled with air By bringing B and C nearer to A another great increase of sensibility was made By enlarging the size of the plates still further power was gained By diminishing the extent of the wires &c, connected with the gold leaves, another improvement resulted So that in fact the gold leaves became, in this manner, as delicate a test of *specific inductive action* as they are, in Bennet's and Singer's electrometers, of ordinary electrical charge

1313 It is evident that by making the three plates the sides of cells, with proper precautions as regards insulation, &c, this apparatus may be used in the ...

... that two metal plates are quite sufficient to form the instrument the state of the single inducteous plate when the dielectric is changed being ... bringing ... wards ... better ... leaf, a ... electro... teous ... ing itse... trometer ...

1315 To increase the effect, a small condenser may be used with great advantage. Thus if, when two inducteous plates are used, a little condenser were put in the place of the gold leaves, I have no ... plat... ... two plates were used, by the

proper application of the condenser the same reduction might take place This expectation is fully justified by an effect already observed and described (1229)

1316. In that case the application of the instrument to very extensive research is evident. Comparatively small masses of dielectrics could be examined, as diamonds and crystals An expectation, that the specific inductive capacity of crystals will vary in different directions, according as the lines of inductive force (1304) are parallel to, or in other positions in relation to the axes of the crystals, can be tested [1] I purpose that these and many other thoughts which arise respecting specific inductive action and the polarity of the particles of dielectric matter, shall be put to the proof as soon as I can find time

1317 Hoping that this apparatus will form an instrument of considerable use, I beg to propose for it (at the suggestion of a friend) the name of *differential inductometer*

Royal Institution, March 29, 1838

[1] Refer for this investigation to 1689—1698 — *Dec* 1838

TWELFTH SERIES

§ 18. *On Induction (continued)* ¶ vii. *Conduction, or Conductive Discharge* ¶ viii. *Electrolytic Discharge* ¶ ix *Disruptive Discharge —Insulation—Spark—Brush—Difference of Discharge at the Positive and Negative Surfaces of Conductors*

RECEIVED JANUARY 11, READ FEBRUARY 8, 1838

1318 I PROCEED now, according to my promise, to examine, by the great facts of electrical science, that theory of induction which I have ventured to put forth (1165, 1295, &c) The principle of induction is so universal that it pervades all electrical phenomena, but the general case which I *purpose at present* to go into consists of insulation traced into and terminating with discharge, with the accompanying effects This case includes the various *modes* of discharge, and also the condition and characters of a current, the elements of magnetic action being amongst the latter I shall necessarily have occasion to speak theoretically, and even hypothetically and though these papers profess to be experimental researches I hope that, considering the facts and investigations contained in the last series in support of the particular view advanced, I shall not be considered as taking too much liberty on the present occasion, or as departing too far from the character which they ought to have, especially as I shall use every opportunity which presents itself of returning to that strong test of truth, experiment.

1319 Induction has as yet been considered in these papers only in cases of insulation, opposed to insulation is *discharge* The action or effect which may be expressed by the general term *discharge*, may take place, as far as we are aware at present, in several modes Thus, that which is called simply *conduction* involves no chemical action, and apparently no displacement of the particles concerned A second mode may be called *electrolytic discharge*, in it chemical action does occur, and particles must, to a certain degree, be displaced A third mode, namely, that by sparks or brushes, may, because of its violent displacement of the particles of the *dielectric* in its course, be called the *disruptive discharge*, and a fourth may, perhaps, be conveniently distinguished for a time by the words *convection, or carrying discharge*, being that in which discharge is effected either by the carrying power of solid particles, or those of gases and liquids Hereafter, perhaps, all these modes may appear as the result of one common principle, but at present they require to be considered apart, and I will now speak of the *first* mode, for amongst all the forms of discharge, that which we express by the term *conduction* appears the most simple and the most directly in contrast with insulation

¶ vii *Conduction, or Conductive Discharge*

1320 Though assumed to be essentially different, yet neither Cavendish nor Poisson attempt to explain by, or even state in, their theories, what the essential difference between insulation and conduction is Nor have I anything, perhaps, to offer in this respect, *except* that, according to my view of induction, insu-

lation and conduction depend upon the same molecular action of the dielectrics concerned, are only extreme degrees of *one common condition or effect*, and in any sufficient mathematical theory of electricity must be taken as cases of the same kind Hence the importance of the endeavour to show the connection between them under my theory of the electrical rela-

ferent, they may be associated by numerous

the whole case

1322 Spermaceti has been examined and found to be a dielectric, through which induction can take place (1240, 1246), its specific inductive capacity being about or above 1 8 (1279), and the inductive action has been considered in it, as in all other substances, an action of contiguous particles

1323 But spermaceti is also a *conductor*,

[...] force has brought the contiguous

and conduction are closely associated together

or rather are extreme cases of one common condition

1325 In ice or water we have a better conductor than spermaceti, and the phenomena of induction and insulation therefore rapidly disappear, because conduction quickly follows upon the assumption of the inductive state But let a plate of cold ice have metallic coatings on its sides, and connect one of these with a good electrical machine in work, and the other with the ground, and it then becomes easy to observe the phenomena of induction through the

sequent discharge due to the conductive act it is succeeded by another portion of force from the machine to restore the inductive state If the ice be converted into water the same suc-

tery be employed

erly separated when we are examining into their nature, that is, into the general law or laws under which their phenomena are produced *They appear to me to consist* in an action of contiguous particles dependent on the forces developed in electrical excitement, these forces bring the particles into a state of tension or polarity, which constitutes both *induction* and *insulation*, and being in this state, the continuous particles have a power or *capability* of communicating their forces one to the other, by which they are lowered, and discharge occurs Every body appears to discharge (444, 987), but the possession of this capability in a *greater or smaller degree* in different bodies, makes them better or worse *conductors*, *worse* or better insulators, and both *induction* and *conduction* appear to be the same in their prin-

in the best cases, in only an almost inse[...]

quantity

[...] to penetrate into

side in harmonious arrangement, is an opinion of long standing, and sanctioned by the ablest philosophers I hope, therefore, I may be excused the attempt to look at the highest cases of conduction as analogous to, or even the same in kind with, those of induction and insulation

1328 If we consider the slight penetration of sulphur (1241, 1242) or shellac (1234) by electricity, or the *feebler insulation sustained by* spermaceti (1240, 1279), as essential consequences and indications of their *conducting* power, then may we look on the resistance of metallic wires to the passage of electricity through them as *insulating* power Of the numerous well known cases fitted to show this resistance in what are called the perfect conductors, the experiments of Professor Wheatstone best serve my present purpose, since they were carried to such an extent as to show that *time* entered as an element into the conditions of conduction[1] even in metals When discharge was made through a copper wire 2640 feet in length, and 1/15th of an inch in diameter, so that the luminous sparks at each end of the wire, and at the middle, could be observed in the same place, the latter was found to be sensibly behind the two former in time, they being by the conditions *of the experiment simultaneous Hence* a proof of retardation and what reason can be given why this retardation should not be of the same kind as that in spermaceti or in lac, or sulphur? But as, in them retardation is insu*lation*, and insulation is induction, why should we refuse the same relation to the same exhibitions of force in the metals?

1329 We learn from the experiment that if *time* be allowed the retardation is gradually overcome, and the same thing obtains for the spermaceti, the lac, and glass (1248) give but time in proportion to the retardation, and the latter is at last vanquished But if that be the case, and all the results are alike in kind the only difference being in the length of time, why should we refuse to metals the previous inductive action, which is admitted to occur in the other bodies? The diminution of *time* is no negation of the action, nor is the lower degree of tension requisite to cause the forces to traverse the metal, as compared to that necessary in the cases of water, spermaceti, or lac These differences would only point to the conclusion, that in metals the particles under induction can transfer their forces when at a lower degree of tension or polarity, and with greater facility than in the instances of the other bodies

[1] *Philosophical Transactions* 1834 p. 583.

1330 Let us look at Mr Wheatstone's beautiful experiment in another point of view If, leaving the arrangement at the middle and two ends of the long copper wire unaltered, we remove the two intervening portions and replace them by wires of iron or platina, we shall have a much greater retardation of the middle spark than before If, removing the iron we were to *substitute for it only five or six feet of water in* a cylinder of the same diameter as the metal, we should have still greater retardation If from water we passed to spermaceti, either directly or by gradual steps through other bodies (even though we might vastly enlarge the bulk, for the purpose of evading the occurrence of a spark elsewhere (1331) than at the three proper intervals), we should have still greater retardation, until at last we might arrive, by degrees so small as to be inseparable from each other, at actual and permanent insulation What, then is to separate the principle of these two extremes perfect conduction and perfect insulation, from each other since the moment we leave in the smallest degree perfection at either extremity, we involve the element of perfection at the opposite end? Especially too, as we have not in nature the case of perfection *either at one extremity or the other, either of* insulation or conduction

1331 Again, to return to this beautiful experiment in the various forms which may be given to it the forces are not all in the wire *(after they have left the Leyden jar) during* the whole time (1328) occupied by the discharge, they are disposed in part through the surrounding dielectric under the well known form of induction and if that dielectric be air, induction takes place from the wire through the air to surrounding conductors, until the ends of the wire are electrically related through its length, and discharge has occurred, i e, *for* the *time* during which the middle spark is retarded beyond the others This is well shown by the old experiment, in which a long wire is so bent that two parts (*Pl* X, *Fig 1*), *a*, *b*, near its extremities shall approach within a short distance, as a quarter of an inch, of each other in the air If the discharge of a Leyden jar, charged to a sufficient degree, be sent through such a wire, by far the largest portion of the electricity will pass as a spark across the air at the interval, and not by the metal Does not the middle part of the wire, therefore, act here as an insulating medium, though it be of metal? and is not the spark through the air an indication of the tension (simultaneous with i

PLATE X

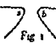


Fig 1

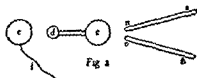


Fig 2

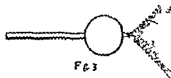


Fig 3



Fig 4



Fig 5

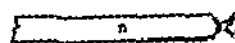


Fig 8

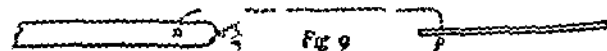


Fig 9

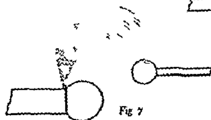


Fig 7

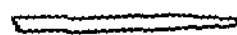


Fig 10

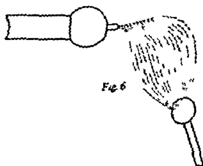


Fig 6

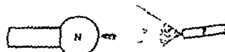


Fig 11



Fig 12

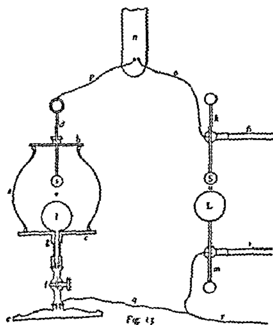


Fig 13

duction) of the electricity in the ends of this single wire? Why should not the wire and the air both be regarded as dielectrics, and the action at its commencement, and whilst there is tension, as an inductive action? If it acts through the contorted lines of the wire, so it also does

charge between the particles whilst in a low state of tension The retardation is for the time insulation, and it seems to me we may just as fairly compare the air at the interval *a b* (*Fig 1*) *and the wire in the circuit, as two bodies of* the same kind and acting upon the same prin-

amount of insulating effect

1332 This comparison is still more striking when we take into consideration the experiment of Mr Harris, in which he stretched a fine wire across a glass globe, the air within being rarefied [3] On sending a charge through the joint arrangement of metal and rare air, as much, if not more, electricity passed by the latter as by the former In the air, rarefied as it was, there can be no doubt the discharge was preceded by induction (1284), and to my mind all the circumstances indicate that the same was the case with the metal, that, in fact, both substances are *dielectrics*, exhibiting the same effects in consequence of the action of the same causes, the only variation being one of degree in the different substances employed

1333 Judging on these principles, velocity of discharge through the *same wire* may be varied greatly by attending to the circumstances which cause variations of discharge through spermaceti or sulphur Thus, for instance, it must vary with the tension or intensity of the first urging force (1234, 1240), which tension is charge and induction *So if the two ends of* the wire, in Professor Wheatstone's experiment, were immediately connected with two large insulated metallic surfaces exposed to the air, so that the primary act of induction, *after* making the contact for discharge, might be in part removed from the internal portion of the wire at the first instant, and disposed for the moment on its surface jointly with the air and surrounding conductors, then I venture to anticipate that the middle spark would be more retarded than before, and if these two plates were the inner and outer coating of a large jar or a Leyden battery, then the retardation of that spark would be still greater

1334 Cavendish was perhaps the first to show distinctly that discharge was not always by one channel,[4] but, if several are present by many at once We may make these different channels of different bodies, and by proportioning *their thicknesses and lengths, may*

therefore separate any one of these bodies from the others, as to the *principles and mode* of insulating and conducting, except by mere degree? All seem to me to be dielectrics acting

[1] These will be examined hereafter (1348 &c)

[2] *Mémoires de l Académie* 1785 p 612, or *Encyclopædia Britannica* (7th edition) First Supplement, Vol I p 611

[3] *Philosophical Transactions* 1834 p 242.

[4] *Philosophical Transactions* 1776 p 197

particles, either of the air or of dust in it It is equally certain, however, that with higher degrees of tension or charge the particles discharge to one another, and that is conduction If the gases possess the power of insulating a certain low degree of tension continuously and perfectly, such a result may be due to their peculiar physical state, and the condition of separation under which their particles are placed But in that, or in any case, we must not forget the fine experiments of Cagniard de la Tour,[1] in which he has shown that liquids and their vapours can be made to pass gradually into each other, to the entire removal of any marked distinction of the two states Thus, hot dry steam and cold water pass by insensible gradations into each other, yet the one is amongst the gases as an insulator and the other a comparatively good conductor As to conducting power, therefore, the transition from metals even up to gases is gradual substances make but one series in this respect, and the various cases must come under one condition and law (444) The specific differences of bodies as to conducting power only serves to strengthen the general argument, that conduction, like insulation, is a result of induction and is an action of contiguous particles

1337 I might go on now to consider induction and its concomitant, conduction through mixed dielectrics, as, for instance, when a charged body, instead of acting across air to a distant uninsulated conductor, acts jointly through it and an interposed insulated conductor In such a case, the air and the conducting body are the mixed dielectrics, and the latter assumes a polarized condition as a mass, like that which my theory assumes each particle of the air to possess at the same time (1679) But I fear to be tedious in the present condition of the subject, and hasten to the consideration of other matter

1338 To sum up, in some degree, what has been said I look upon the first effect of an excited body upon neighbouring matters to be the production of a polarized state of their particles which constitutes induction and this arises from its action upon the particles in immediate contact with it, which again act upon those contiguous to them, and thus the forces are transferred to a distance If the induction remain undiminished, then perfect insulation is the consequence and the higher the polarized condition which the particles can acquire or maintain, the higher is the intensity which may be given to the acting forces If, on the contrary, the contiguous particles, upon acquiring the polarized state, have the power to communicate their forces, then conduction occurs, and the tension is lowered, conduction being a distinct act of discharge between neighbouring particles The lower the state of tension at which this discharge between the particles of a body takes place, the better conductor is that body In this view, insulators may be said to be bodies whose particles can retain the polarized state, whilst conductors are those whose particles cannot be permanently polarized If I be right in my view of induction, then I consider the reduction of these two effects (which have been so long held distinct) to an action of contiguous particles obedient to one common law, as a very important result, and, on the other hand, the identity of character which the two acquire when viewed by the theory (1326), is additional presumptive proof in favour of the correctness of the latter

1339 That heat has great influence over simple conduction is well known (445), its effect being in some cases, almost an entire change of the characters of the body (432, 1340) Harris has, however, shown that it in no respect affects gaseous bodies, or at least air,[2] and Davy has taught us that, as a class, metals have their conducting power diminished by it[3]

1340 I formerly described a substance, sulphuret of silver, whose conducting power was increased by heat (433, 437, 438), and I have since then met with another as strongly affected in the same way this is fluoride of lead When a piece of that substance, which had been fused and cooled, was introduced into the circuit of a voltaic battery, it stopped the current. Being heated, it acquired conducting powers before it was visibly red hot in daylight and even sparks could be taken against it whilst still solid The current alone then raised its temperature (as in the case of sulphuret of silver) until it fused, after which it seemed to conduct as well as the metallic vessel containing it for whether the wire used to complete the circuit touched the fused fluoride only, or was in contact with the platina on which it was supported, no sensible difference in the force of the current was observed During all the time there was scarcely a trace of decomposing

[1] *Annales de Chimie* XXI pp 127 178 or *Quarterly Journal of Science*, XV, 145.

[2] *Philosophical Transactions* 1834 p. 230.

[3] *Ibid.*, 1821 p 431.

action of the fluoride and what did occur seemed referable to the air and moisture of the atmosphere and not to electrolytic action

1341 I have now very little doubt that per iodide of mercury (414 448 691) is a case of the same kind and also corrosive sublimate (692) I am also inclined to think since making the above experiments that the anomalous ac t on of the protoxide of antimony formerly observed and described (693 801) may be referred in part to the same cause

1342 I have no intention at present of going into the particular relation of heat and elec tr city but we may hope hereafter to d scover by experiment the law which probably holds together all the above effects with those of the

¶ viii *Electrolytic Discharge*

1343 *I have already expressed in a former* paper (1164) the view by which I hope to associate ordinary induction and electrolyzation Under that view the discharge of electric forces by electrolyzation is rather an effect superadd ed in a certain class of bodies to those already descr bed as constituting induction and insu lat on than one independent of and distinct from these phenomena

1344 Electrolytes as respects their insulat-

occur being in so small a proportion as to be almost unimportant When liquefied they also belong to the same l st whilst the electric in tens ty is below a certain degree but at a given intensity (910 912 1007) fixed for each and very low in all known cases they play a new part causing discharge in proportion (783) to

by themselves The former phenomena have

increase the tension indicative of this state of induction and so make the state itself more evi lent Thus if distilled water be employed and a long narrow portion of it placed between the electrodes of a powerful voltaic battery we have at once indications of the intensity which

diverged and Leyden bottles charged at their wires The water is in the condition of the sper maceti (1322 1323) a bad conductor and a bad insulator but what it does insulate is by virtue

tion of tl e inductive tension to a certain degree shows (time entering in each case as an important element of the result) that when

mere interchange of their powers or forces at

dielectric The latter is always a compound

[1] See 1609—1708 —*Dec* 1838
[2] *Annales de Chimie* LVIII 60 and LXIII 20

easily be compared to a series of metallic conductors under inductive action, which, whilst in that state, are divisible into these elementary moveable halves

1348 Electrolytic discharge depends, of necessity, upon the non-conduction of the dielectric as a whole, and there are two steps or acts in the process first a polarization of the molecules of the substance and then a lowering of the forces by the separation, advance in opposite directions, and recombination of the elements of the molecules, these being, as it were, the halves of the originally polarized conductors or particles

1349 These views of the decomposition of electrolytes and the consequent effect of discharge, which, as to the particular case, are the same with those of Grotthuss (481) and Davy (482), though they differ from those of Biot (487), De la Rive (490), and others, seem to me to be fully in accordance not merely with the theory I have given of induction generally (1165), but with all the known *facts* of common induction, conduction, and electrolytic discharge, and in that respect help to confirm in my mind the truth of the theory set forth The new mode of discharge which electrolyzation presents must surely be an evidence of the *action of contiguous particles* and as this appears to depend directly upon a previous inductive state, which is the same with common induction, it greatly strengthens the argument which refers induction in all cases to an action of contiguous particles also (1295, &c)

1350 As an illustration of the condition of the polarized particles in a dielectric under induction, I may describe an experiment Put into a glass vessel some clear rectified oil of turpentine, and introduce two wires passing through glass tubes where they coincide with the surface of the fluid, and terminating either in balls or points Cut some very clean dry white silk into small particles, and put these also into the liquid then electrify one of the wires by an ordinary machine and discharge by the other The silk will immediately gather from all parts of the liquid, and form a band of particles reaching from wire to wire, and if touched by a glass rod will show considerable tenacity, yet the moment the supply of electricity ceases, the band will fall away and disappear by the dispersion of its parts The *conduction* by the silk is in this case very small, and after the best examination I could give to the effects, the impression on my mind is, that the adhesion of the whole is due to the polarity which each filament acquires, exactly as the particles of iron between the poles of a horseshoe magnet are held together in one mass by a similar disposition of forces The particles of silk therefore represent to me the condition of the molecules of the dielectric itself, which I assume to be polar, just as that of the silk is In all cases of conductive discharge the contiguous polarized particles of the body are able to effect a neutralization of their forces with greater or less facility, as the silk does also in a very slight degree Further we are not able to carry the parallel, except in imagination; but if we could divide each particle of silk into two halves and let each half travel until it met and united with the next half in an opposite state it would then exert its carrying power (1347) and so far represent electrolytic discharge

1351 Admitting that electrolytic discharge is a consequence of previous induction, then how evidently do its numerous cases point to induction in curved lines (521, 1216), and to the divergence or lateral action of the lines of inductive force (1231), and so strengthen that part of the general argument in the former paper[1] If two balls of platina, forming the electrodes of a voltaic battery, are put into a large vessel of dilute sulphuric acid, the whole of the surfaces are covered with the respective gases in beautifully regulated proportions, and the mind has no difficulty in conceiving the direction of the curved lines of discharge, and even the intensity of force of the different lines by the quantity of gas evolved upon the different parts of the surface From this condition of the lines of inductive force arise the general effects of diffusion the appearance of the anions or cathions round the edges and on the farther side of the electrodes when in the form of plates, and the manner in which the current or discharge will follow all the forms of the electrolyte however contorted Hence, also, the effects which Nobili has so well examined and described[1] in his papers on the distribution of currents in conducting masses All these effects indicate the curved direction of the currents or discharges which occur in and through the dielectrics, and these are in every case preceded by equivalent inductive actions of the contiguous particles

1352 Hence also the advantage, when the exciting forces are weak or require assistance, of enlarging the mass of the electrolyte, of increasing the size of the electrodes, of making the coppers surround the zincs all is in har-

[1] *Bibliothèque Universelle* 1835, LIX, 263, 416.

mony with the view of induction which I am endeavouring to examine, I do not perceive as yet one fact against it

1353 There are many points of *electrolytic discharge* which ultimately will require to be very closely considered, though I can but slightly touch upon them It is not that, as far as I have investigated them, they present any contradiction to the view taken (for I have carefully, though unsuccessfully, sought for such cases), but simply want of time as yet to pursue the inquiry, which prevents me from entering upon them here

1354 One point is, that different electrolytes or dielectrics require different initial intensities for their decomposition (912) This may depend upon the degree of polarization which the particles require before electrolytic discharge commences It is in direct relation to the chemical affinity of the substances concerned, and will probably be found to have a relation or analogy to the specific inductive capacity of different bodies (1252, 1296) It thus promises to assist in causing the great truths of those extensive sciences, which are occupied in considering the forces of the particles of matter, to fall into much closer order and arrangement than they have heretofore presented

1355 Another point is the facilitation of electrolytic conducting power or discharge by the addition of substances to the dielectric employed This effect is strikingly shown where water is the body whose qualities are improv-

change sensible to the voltameter (739) Ammonia produces no effect, but its carbonate does *The caustic alkalies and their carbonates* produce a fair effect Sulphate of soda, nitre (753), and many soluble salts produce much effect Percyanide of mercury and corrosive sublimate produce no effect, nor does iodine,

powers of the voltaic battery, and yet both gives and receives power when associated with water M de la Rive has pointed this result out in sulphurous acid,[1] iodine and bromine,[2] the chloride of arsenic produces the same effect A far more striking case, however, is presented by that very influential body, sulphuric acid (681) and probably phosphoric acid also is in the same peculiar relation

1356 It would seem in the cases of those

electrolyte, for whether little or much improved, the decomposition is proportionate to the quantity of electricity passing (727, 730), and the transfer is therefore due to electrolytic discharge This is in accordance with the fact

ities

1357 I have described in the last paper,

these substances, when gaseous, are non-con-

tion requires

[1] *Quarterly Journal* XXVII 407 or *Bibliothèque Universelle* XL, 205 Kemp says sulphurous acid is a very good conductor *Quarterly Journal* 1831 p 613

[2] *Quarterly Journal* XXIV, 465 or *Annales de Chimie* XXXV, 161

[3] *Philosophical Transactions* 1827, p 22

a hundredfold or more (419) It not only es tablishes a very general relation between the physical properties of these bodies and electricity acting by induction through them but draws both their physical and chemical rela tions so near together as to make us hope we shall shortly arrive at the full comprehension of the influence they mutually possess over each other

¶ ix *Disruptive Discharge and Insulation*

1359 The next form of discharge has been distinguished by the adjective *disruptive* (1319) as it in every case displaces more or less the

which though frequently accompanying the former are essentially distinct in their nature

1360 The conditions requisite for the production of an electric spark in its simplest form are well known An insulating dielectric must be interposed between two conducting surfaces in opposite states of electricity and then if the actions be continually increased in strength or otherwise favoured either by exalting the electric state of the two conductors or bringing them nearer to each other or diminishing the density of the dielectric a *spark* at last appears and the two forces are for the time annihilated for *discharge* has occurred

1361 The conductors (which may be con sidered as the termini of the inductive action) are in ordinary cases most generally metals whilst the dielectrics usually employed are com mon air and glass In my view of induction however, every dielectric becomes of impor tance for as the results are considered essen *tially dependent on these bodies it was to* be expected that differences of action never before suspected would be evident upon close exam

properties

1362 All the effects prior to the discharge are inductive and the degree of tension which

portant point It is the limit of the influence

therefore a representative of the intensity of the electric forces in activity

1363 Many philosophers have examined the circumstances of this limiting action in a r but as far as I know none has come near Mr Harris as to the accuracy with and the extent to which he has carried on his investigations[1] Some of his results I must very briefly notice premising that they are all obtained with the use of air as the *dielectric* between the conducting surfaces

1364 First as to the *distance* between the two balls used or in other words the *thickness* of the dielectric across which the induction was sustained The quantity of electricity measured by a unit jar or otherwise on the same

charging points and that under very varied and exact forms of experiment[2]

1365 Then with respect to variation in the *pressure* or *density* of the air The quantities of electricity required to produce discharge across a *constant* interval varied exactly with varia

whilst the interval and density of the air were varied then these were found in the inverse simple ratio of each other the same quant ty passing across twice tl e distance with air rarefied to one-half[3]

1366 It must be remembered that these ef *fects take place without any* variation of tl e *inductive* force by condensation or rarefaction of the air That force remains the same in a r[4] and in all gases *(1284 1292), whatever* their rarefaction may be

1367 Variation of the *temperature* of the a r produced no variation of the quantity of electricity required to cause discharge across a given interval[5]

Such are the general results which I have occasion for at present obtained by Mr Harris and they appear to me to be unexceptionable

[1] *Philosophical Transactions* 1834 p 225.
[2] *Ibid* p 2 5
[3] *Ibid* p ??)
[4] *Ibid* pp ?37 244
[5] *Ibid* p 230

1368 In the theory of induction founded upon a molecular action of the dielectric, we have to look to the state of that body principally for the cause and determination of the above effects Whilst the induction continues it is assumed that the particles of the dielectric are in a certain polarized state the tension of this state rising higher in each particle as the induction is raised to a higher degree either by approximation of the inducing surfaces variation of form increase of the original force or other means until at last the tension of the particles having reached the utmost degree which they can sustain without subversion of the whole arrangement discharge immediately after takes place

1369 The theory does not assume however that *all* the part cles of the dielectric subject to the inductive action are affected to the same amount or acquire the same tension What has been called the lateral action of the lines of inductive force (1231 1297) and the diverging and occasionally curved form of these lines is against such a notion The idea is that any

and that therefore the whole amount of tension for each such section would be the same

1370 Discharge probably occurs not when all the particles have attained to a certain degree of tension but when that particle which is most affected has been exalted to the subverting or turning point (1410) For though *all* the particles in the line of induction resist charge and are associated in their actions so as to give a sum of resisting force yet when any one is brought up to the overturning point *all* must give way in the case of a spark between ball and ball The breaking down of that one must of necessity cause the whole barrier to be overturned for it was in its utmost degree of resistance when it possessed the aiding power of that one part cle in addition to the power of

amount in them of forced variation from their normal state (1298 1368)

1371 The whole effect produced by a charged conductor on a distant conductor insulated or not is by my theory assumed to be due to an action propagated from particle to particle of the intervening and insulating dielectric all the particles being considered as thrown for the time into a forced condition from which they endeavour to return to their normal or natural state The theory therefore seems to supply an easy explanation of the influence of *distance* in affecting induction (1303 1364) As the distance is dimin shed induction increases for there are then fewer particles in the line of inductive force to oppose their united resistance to the assumption of the forced or polar

to d scharge across the first interval is sufficient to strike across the second and it is evident also that at tl at time there are only half the number of interposed molecules uniting their

in its supply to lower the intens ty of act on and this follows as a very natural consequence

cs of such area twice or three times the number of molecules of the dielectric are brought into the polarized condition and employed in sustaining the inductive action and consequently the tension belonging to the smaller number on which the limited force was originally accumulated must fall in a proportionate degree

bulging as it were of the lines of inductive

[1] See Harris on proposed part cular meaning of these terms *Philosophical Transactions* 1834 p 22

tion with my theory (1302) For in the latter case, the small surface *p* is affected only by those particles which are brought into the inductive condition by the equally small surface of the opposed conductor, whereas when that is a ball or plate the lines of inductive force from the latter are concentrated, as it were, upon the end *p* Now though the molecules of the dielectric against the large surface may have a much lower state of tension than those against the corresponding smaller surface, yet they are also far more numerous, and, as the lines of inductive force converge towards a point, are able to communicate to the particles contained in any cross section (1369) nearer the small surface an amount of tension equal to their own, and consequently much higher for each individual particle, so that, at the surface of the smaller conductor, the tension of a particle rises much, and if that conductor were [illegible]

&c)

1375 *Rarefaction* of the air does not alter the *intensity* of inductive action (1284, 1287), nor is there any reason, as far as I can perceive, why it should If the quantity of electricity and the distance remain the same, and the air be rarefied one-half, then, though one-half of the particles of the dielectric are removed, the [illegible]

[illegible] rarefied atmosphere as [illegible]

on the surface of conductors in air to the *pressure of the atmosphere* (1305) The latter is the view which, being adopted by Poisson and Biot,[1] is also, I believe, that generally received, and it associates two such dissimilar things, as the ponderous air and the subtile and even hypothetical fluid or fluids of electricity, by gross mechanical relations, by the bonds of mere static pressure My theory, on the contrary, sets out at once by connecting the electric forces with the particles of matter, it derives all its proofs, and even its origin in the first instance, from experiment, and then, without any further assumption, seems to offer at once a full explanation of these and many other singular, peculiar, and, I think, heretofore unconnected effects

1378 [illegible]

sider an insulated sphere electrified positively and placed in the centre of another and larger [illegible]

duce such a dielectric as sulphur or lac, into the space between the two conductors on one side only, or opposite one part of the inner [illegible]

phere remain *perfectly* unchanged

1379 Fusinieri took a different view from that of Poisson, Biot, and others, of the reason why rarefaction of air caused easy diffusion of electricity He considered the effect as due to the removal of the *obstacle* which the air presented to the expansion of the substances from which the electricity passed[2] But platina balls show the phenomena *in vacuo* as well as volatile metals and other substances, besides which, when the rarefaction is very considerable, the electricity passes with scarcely any resistance and the production of no sensible heat, so that I think Fusinieri's view of the matter is likely to gain but few assents

1380 I have no need to remark upon the discharging or collecting power of flame or hot air I believe, with Harris, that the mere heat

[1] *Encyclopædia Britannica* [7th edition] Supplement Vol. IV, Article *Electricity* pp 76, 81, &c.
[2] *Bib Univ*, 1831, XLVIII, 375.

time are associated with it, are fully sufficient to account for all the effects

1381 We have now arrived at the important question, how will the inductive tension requisite for insulation and disruptive discharge be sustained in gases, which, having the same physical state and also the *same pressure* and the *same temperature* as air, differ from it in specific gravity, in chemical qualities, and it may be in *peculiar relations*, which not being as yet recognized, are purely electrical (1361)?

1382 Into this question I can enter now only as far as is essential for the present argument, namely, that insulation and inductive tension do not depend merely upon the charged conductors employed, but also, and essentially,

ground at the top and bottom so as to be closed by two ground brass plates, *b* and *c*, *b* carried a stuffing box, with a sliding rod *d* terminated by a brass ball *s* below, and a ring above The lower plate was connected with a foot, stopcock, and socket, *e*, *f* and *g*, and also with a brass ball *l*, which by means of a stem attached

was well-covered with a coat of shellac previously dissolved in alcohol On exhausting the vessel at the air-pump it could be filled with

were fixed two brass balls, and through these

Ball *s*	0 93 of an inch
Ball S	0 96 of an inch
Ball *l*	2 02 of an inch
Ball L	1 95 of an inch
Interval v	*0 62 of an inch*

1386 On proceeding to experiment it was found that when air or any gas was in the receiver *a*, the interval *u* was not a fixed one, it might be altered through a certain range of distance, and yet sparks pass either there or at *v* in the receiver The extremes were therefore noted, i e the greatest distance short of that at which the discharge *always* took place at *v* in the gas, and the least distance short of that at which it *always* took place at *u* in the air Thus, with air in the receiver, the extremes at *u* were 0 56 and 0 79 of an inch, the range of 0 23 between these distances including intervals at which sparks passed occasionally either at one place or the other

1387 The small balls *s* and S could be rendered either positive or negative from the machine, and as gases were expected and were found to differ from each other in relation to this change (1399), the results obtained under these differences of charge were also noted

1388 The following is a table of results, the gas named is that in the vessel *a* The smallest, greatest, and mean interval at *u* in air is expressed in parts of an inch, the interval *v* being constantly 0 62 of an inch

	Smallest	Greatest	Mean
Air, *s* and S, pos	0 60	0 79	0 695
Air, *s* and S, neg	0.59	0 68	0 635
Oxygen, *s* and S pos.	0 41	0 60	0 505
Oxygen, *s* and S, neg	0 50	0 52	0 510
Nitrogen, *s* and S, pos	0 55	0 68	0 615
Nitrogen, *s* and S, neg	0 59	0 70	0 645

(Continued on next page)

(*Continued*)

	Smallest	Greatest	Mean
Hydrogen *s* and S pos	0 30	0 44	0 370
Hydrogen *s* and S neg	0 25	0 30	0 275
Carbonic acid *s* and S pos	0 56	0 72	0 640
Carbonic acid *s* and S neg	0 58	0 60	0 590
Olefiant gas *s* and S pos	0 64	0 86	0 750
Olefiant gas *s* and S neg	0 69	0 77	0 730
Coal gas *s* and S pos	0 37	0 61	0 490
Coal gas *s* and S neg	0 47	0 58	0 525
Muriat c acid gas *s* and S pos	0 89	1 32	1 105
Muriatic acid gas *s* and S neg	0 67	0 75	0 720

1389 The above results were all obtained at one time On other occasions other experiments were made which gave generally the same results as to order though not as to numbers Thus

Hydrogen *s* and S pos	0 23	0 57	0 400
Carbonic acid *s* and S pos	0 51	1 05	0 780
Olefiant gas *s* and S pos	0 66	1 27	0 965

I did not notice the difference of the barometer on the days of experiment [1]

1390 One would have expected only two distances one for each interval for which the d scharge might happen either at one or the other and that the least alteration of e ther would immediately cause one to predominate constantly over the other But that under com mon circumstances is not the case With air in the receiver the variat on amounted to 0 2 of an inch nearly on the smaller interval of 0 6 and with muriatic acid gas the variation was above 0 4 on the smaller interval of 0 9 Why is it that when a fixed interval (the one in the receiver)

charged condition of the surface of the glass vessel *a* That the whole of the effect is not traceable to the influence of circumstances in the vessel *a* may be deduced from the fact that when sparks occur between balls in free air they frequently are not straight and often pass otherwise than by the shortest distance

1392 When a spark had passed at either in terval then generally more tended to appear at the *same* interval as if a preparat on had been made for the passing of the latter sparks So also on continuing to work the machine quickly the sparks generally followed at the same place This effect is probably due in part to the warmth of the air heated by the preced

constant in its direction occurs when the electricity communicated to the balls *s* and S is changed from positive to negative or in the contrary direction It is that the range of va

	Pos	Neg
In A r the range was	0 19	0 09
Oxygen	0 19	0 02
Nitrogen	0 13	0 11
Hydrogen	0 14	0 05
Carbonic acid	0 16	0 02
Olefiant gas	0 22	0 08
Coal gas	0 24	0 12
Muriat c acid	0 43	0 08

I have no doubt these numbers require cons d erable correction but the general result is strik ing and the differences in several cases very great

of the varia-

vessel yet we may for present purposes use the mean interval as representing in some de-

(1302) of hydrogen gas ... of oxygen nitrogen or air

[1] S milar experiments n d fferent gases are described at 1507 1508 —*Dec* 1838

1396 Yet it is evident that the difference is not due to specific gravity, for though hydrogen is the lowest, and therefore lower than oxygen, oxygen is much beneath nitrogen, or olefiant gas and carbonic acid gas though considerably heavier than olefiant gas or muriatic acid gas, is lower than either Oxygen as a heavy, and olefiant as a light gas, are in strong contrast with each other, and if we may reason of olefiant gas from Harris' results with air [illegible]

same density nor pressure as oxygen would have equal insulating powers with it, or equal tendency to resist discharge

1397 Experiments have already been described (1291, 1292) which show that the gases are sensibly alike in their inductive capacity This result is not in contradiction with the existence of great differences in their restraining power The same point has been observed already in regard to dense and rare air (1375)

1398 Hence arises a new argument proving that it cannot be mere pressure of the atmosphere which prevents or governs discharge [illegible]

inductive action

1399 Other specific differences amongst the gases may be drawn from the preceding series [illegible]

numbers are lower than the positive (1393), but besides that the *order* of the positive and negative results is not the same Thus on comparing [illegible]

1400 So also when the conductor *n* was con [illegible]

when positive for in the latter case, much of the electricity passed off as brush discharge through the air from the connecting wire *p*, but in the former case it all seemed to go through the muriatic acid

1401 The consideration, however, of positive and negative discharge across air and other gases will be resumed in the further part of this, or in the next paper (1465, 1525)

1402 Here for the present I must leave this part of the subject, which had for its object only to observe how far gases agreed or differed as to their power of retaining a charge on bodies acting by induction through them All the results conspire to show that induction is [illegible]

greatly assist in developing the specific properties of each gaseous dielectric at the same [illegible]

body used will produce some effect for though the production of the polarized states in the

particle of a solid may not be obstructed, but, on the contrary, may in some cases be even favoured (1164, 1344) by its solidity or other circumstances, yet solidity may well exert an influence on the point of final subversion (just as it prevents discharge in an electrolyte), and so enable inductive intensity to rise to a much higher degree

1404 In the cases of solids and liquids too, bodies may, and most probably do, possess specific differences as to their ability of assuming *the polarized* state, and also *as to the extent to* which that polarity must rise before discharge occurs An analogous difference exists in the specific inductive capacities already pointed out in a few substances (1278) in the last paper Such a difference might even account for the various degrees of insulating and conducting power possessed by different bodies, and, if it should be found to exist, would add further strength to the argument in favour of the molecular theory of inductive action

1405 Having considered these various cases of sustained insulation in non-conducting di electrics up to the highest point which they *can attain we find* that *they terminate at last in disruptive discharge* the peculiar condition of the molecules of the dielectric which was necessary to the continuous induction, being equally essential to the occurrence of that ef fect which closes all the phenomena This discharge is not only in its appearance and condi tion different to the former modes by which the lowering of the powers was effected (1320, 1343), but, whilst really the same in principle, varies much from itself in certain characters, and thus presents us with the forms of *spark*, *brush*, and *glow* (1359) I will first consider *the spark*, *limiting it for the* present to the case of discharge between two oppositely electrified conducting surfaces.

The Electric Spark or Flash

1406 The *spark* is consequent upon a dis charge or lowering of the polar- state of — ular a(a very polariz norm th wi *...ather to continue* (1417—1430) the discharge effect in the — the —

discharge occurs are not merely pushed apart, but assume a peculiar state, a highly exalted condition for the time i e, have thrown upon them all the surrounding forces in succession and rising up to a proportionate intensity of condition, perhaps equal to that of chemically combining atoms, discharge the powers, pos sibly in the same manner as they do theirs by some operation at present unknown to us and so the end of the whole The *ultimate effect is* exactly as if a metallic wire had been put into *the place of the discharging particles, and it* does not seem impossible that the principles of *action in both cases, may, hereafter, prove to* be the same

1407 The *path of the spark*, or of the discharge, depends on the degree of tension ac quired by the particles in the line of discharge circumstances, which in every common case are very evident and by the theory easy to un derstand, rendering it higher in them than in their neighbours, and, by exalting them first *to the requisite condition, causing them to de*termine the course of the discharge Hence the *selection of the path and the solution of the* wonder which Harris has so well described[1] as *existing under the old theory All is prepared* amongst the molecules beforehand, by the pri *or induction, for the path either of the electric* spark or of lightning itself

1408 The same difficulty is expressed as a principle by Nobili for voltaic electricity, al most in Mr Harris's words namely,[2] elec tricity directs itself towards the point *where it* can most easily discharge itself," and the results of this as a principle he has well *wrought* out for the case of volt — *solutio* of the c *particle* tension it, is th ...arge first and most efficiently performed

1409 The *moment of discharge is* probably determined by that molecule of the dielectric which, from the — most sity from ... this molecule must be on the surface of one of them, but when it passes between a conductor and a non-conductor, it is, perhaps, not always so (1453) When this particle has acquired its maximum tension, then the whole barrier of resistance is

[1] *Nautical Magazine* 1834 p 229
[2] *Bibliothèque Universelle* 1835, LIX 275.

broken down in the line or lines of inductive action originating at it, and disruptive discharge occurs (1370) and such an inference, drawn as it is from the theory, seems to me in accordance with Mr. Harris' facts and conclusions respecting the resistance of the atmosphere, namely, that it is not really greater at any one discharging distance than another [1]

1410 It seems probable that the tension of a particle of the same dielectric, as air, which is requisite to produce discharge, is a *constant quantity*, whatever the shape of the part of the conductor with which it is in contact, whether ball or point; whatever the thickness or depth of dielectric throughout which induction is exerted, perhaps, even, whatever the state, as to rarefaction or condensation of the dielectric, and whatever the nature of the conductor, good or bad, with which the particle is for the moment associated In saying so much, I do not mean to exclude small differences which may

the definiteness of the power possessed by a particular molecule, may we not hope to find an immediate relation to the force which, being electrical, is equally definite and constitutes chemical affinity?

1411. Theoretically it would seem that, at the moment of discharge by the spark in one line of inductive force, not merely would all the other lines throw their forces into this one

on the trans-

ready described (1297), I was desirous, by va-

electricity [2]

[1] *Philosophical Transactions* 1834 pp 227, 229

[2] See further investigations of this subject, 1655–1666, 1709–1735 —*Dec* 1838

1412 Amongst other results, I expected and sought for the mutual affection, or even the lateral coalition of two similar sparks, if they could be obtained simultaneously side by side, and sufficiently near to each other For this

The jars were placed upon a sheet of tinfoil, and so adjusted that their rods, *a* and *b*, were near together, in the position represented in plan (Pl X, *Fig* 2) *c* and *d* were two brass

ed metal rod across from *a* to *b*, charging the

neous

1413 Under these circumstances two modes of discharge took place, either each end had its own particular spark to the ball, or else one end only was associated by a spark with the ball, but was at the same time related to the other end by a spark between the two

1414 When the ball *c* was about an inch in diameter, the ends *n* and *o*, about *half* an inch from it, and about 0 4 of an inch from each other, the two sparks to the ball could be obtained When for the purpose of bringing the

electricity.

neous separate sparks closer together, until, at last, the distance between them was not more at the widest part than 0 6 of their whole length

1416 Numerous sparks were then passed and *carefully observed* They were very rarely straight, but either curved or bent irregularly In the average of cases they were, I think, decidedly convex towards each other, perhaps *two thirds presented more or less of this effect*, the rest bulging more or less outwards I was never able, however, to obtain sparks which, separately leaving the ends of the wires *n* and *o*, conjoined into one spark before they reached or communicated with the ball *c* At present, therefore, though I think I saw a tendency in the sparks to unite, I cannot assert it as a fact

1417 But there is one very interesting effect here, analogous to, and it may be in part the same with, that I was searching for I mean the *increased facility of discharge where the spark* passes For instance, in the cases where one end, as *n*, discharged the electricity of both ends to the ball *c* (Pl XII, *Fig 2*), the electricity *of the other end o, had to pass through an* interval of air 1 5 times as great as that which it might have taken, by its direct passage between the end and the ball itself In such cases, the eye could not distinguish, *even by the use* of Wheatstone's means,[1] that the spark from the end *n*, which contained both portions of electricity, was a double spark. It could not have consisted of two sparks taking separate courses, for such an effect would have been visible to the eye, but it is just possible, that the spark of the first end *n* and its jar, passing at the smallest interval of time before that of the other *o*, had heated and expanded the air in its course, and made it so much more favourable to discharge, that the electricity of the end *o* preferred leaping across to it and taking a very circuitous route, rather than the more direct one to the ball It must, however, be remarked, in answer to this supposition, that the one spark between *d* and *e* would, by its influence, tend to produce simultaneous discharges at *n* and *o*, and certainly did so, when no preponderance was given to one wire over the other, as to the previous inductive effect (1414)

1418 The fact, however, is that disruptive discharge is favourable to itself It is at the outset a case of tottering equilibrium and *if time be an element in discharge, in however* minute a proportion (1436), then the commencement of the act at any point favours its continuance and increase there, and *portions of power* will be discharged by a course which they would not otherwise have taken.

1419 The mere heating and expansion of the air itself by the first portion of electricity which passes, must have a great influence in producing this result

1420 As to the result itself, we see its effect in every electric spark, for it is not the whole quantity which passes that determines the discharge, but *merely that* small portion of force which brings the deciding molecule (1370) up to its maximum tension, then, when its forces are subverted and discharge begins, all the rest passes by the same course, *from the influence* of the favouring circumstances just referred to, and whether it be the electricity on a square inch, or a thousand square inches of charged *glass, the discharge is complete Hereafter* we shall find the influence of this effect in the formation of brushes (1435), and it is not impossible that we may trace it producing the jagged *spark and the forked lightning*

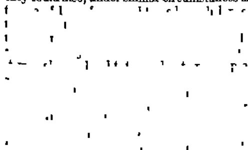
1421 The characters of the electric spark in *different gases* vary, and the variation *may* be due simply to the effect of the heat evolved at the moment. But it may also be due to that specific relation of the particles and the electric forces which I have assumed as the basis of a theory of induction, the facts do not oppose such a view, and in that view the variation strengthens the argument for molecular action, as it would seem to show the influence of the latter in every part of the electrical effect (1423, 1454)

1422 The appearances of the sparks in different gases have often bee[illegible]
cord[illegible]
brief [illegible]
taine[illegible] (platina surfaces would have been better), and at common pressures In *air*, the sparks have that intense light and bluish colour which are so well known, and often have faint or dark parts in *their course*, when the quantity of electricity passing is not great In *nitrogen*, they are very beautiful, *having the same general appearance as in air*, but have decidedly more colour of a bluish or purple character, and I thought were remarkably sonorous In *oxygen*, the sparks were whiter than in air or nitrogen, and I think not so brilliant. In *hydrogen*, they had a very fine crimson colour, not due to its rarity, for the character

[1] *Philosophical Transactions*, 1834 pp 584, 585.

* See Van Marum s description of the Teylerian machine Vol I p 112 and Vol II p 196 also *Encyclopædia Britannica* (7th edition) Vol VI Article *Electricity* pp 505 507

passed away as the atmosphere was rarefied (1459)[1] Very little sound was produced in this gas but that is a consequence of its physical condition[2] In *carbonic acid gas*, the colour was similar to that of the spark in air, but with a little green in it the sparks were remarkably irregular in form, more so than in common air they could also, under similar circumstances as



one part was green and another red black parts also occur very suddenly in the line of the spark, i e, they are not connected by any dull part with bright portions, but the two seem to join directly one with the other

1423 These varieties of character impress my mind with a feeling that they are due to a direct relation of the electric powers to the particles of the dielectric through which the

its passage (1454)

1424 The spark may be obtained in media which are far denser than air, as in oil of turpentine, olive oil, resin glass &c it may also be obtained in bodies which being denser likewise approximate to the condition of conductors as spermaceti water &c But in these cases nothing occurs which, as far as I can perceive, is at all hostile to the general views I have endeavoured to advocate.

The Electric Brush

[1] Van Marum says they are about four times as large in hydrogen as in air Vol I p 122

[2] Leslie *Cambridge Phil Transactions* 267

the termination may be smaller and of badly conducting matter, as wood or sparks may be taken between the prime conductor of the machine and the secondary conductor to which the termination giving brushes belongs or, which gives to the brushes exceedingly fine characters and great magnitude the air around the termination may be rarefied more or less, either by heat or the air pump, the former *favourable circumstances* being also continued

1426 The brush when obtained by a powerful machine on a ball about 0 7 of an inch in diameter at the end of a long brass rod attached to the positive prime conductor, had

each elementary brush being the result of a

they did not become more indefinite in shape,

[1] *Philosophical Transactions* 1834 p. 586.

1429 On using a smaller ball, the general brush was smaller, and the sound, though weaker, more continuous On resolving the brush into its elementary parts, as before, these were found to occur at much shorter intervals of time than in the former case, but still the discharge was intermitting

1430 Employing a wire with a round end, the brush was still smaller, but, as before, separable into successive discharges The sound, though feebler, was higher in pitch, being a distinct musical note

1431 The sound is, in fact due to the recurrence of the noise of each separate discharge, and these, happening at intervals nearly equal under ordinary circumstances, cause a definite note to be heard, which, rising in pitch with the increased rapidity and regularity of the intermitting discharges, gives a ready and accurate measure of the intervals, and so may be used in any case when the discharge is heard, even though the appearances may not be seen, to determine the element of *time* So when, by bringing the hand towards a projecting rod or ball, the pitch of the tone produced by a brushy discharge increases, the effect informs us that we have increased the induction (1374), and by that means increased the rapidity of the alternations of charge and discharge

1432 By using wires with finer terminations, smaller brushes were obtained, until they could hardly be distinguished as brushes, but as long as *sound* was heard, the discharge could be ascertained by the eye to be intermitting, and when the sound ceased, the light became *continuous* as a glow (1359, 1405, 1526—1543)

1433 To those not accustomed to use the eye in the manner I have described, or, in cases where the recurrence is too quick for any unassisted eye, the beautiful revolving mirror of Professor Wheatstone[1] will be useful for such developments of condition as those mentioned above Another excellent process is to produce the brush or other luminous phenomenon on the end of a rod held in the hand opposite to a charged positive or negative conductor, and then move the rod rapidly from side to side whilst the eye remains still The successive discharges occur of course in different places, and the state of things before, at, and after a single coruscation or brush can be exceedingly well separated

1434. The *brush* is in reality a discharge between a bad or a non-conductor and either a conductor or another non-conductor Under common circumstances, the brush is a discharge between a conductor and air, and I conceive it to take place in something like the following manner When the end of an electrified rod projects into the middle of a room, induction takes place between it and the walls of the room, across the dielectric, air, and the lines of inductive force accumulate upon the end in greater quantity than elsewhere, or the particles of air at the end of the rod are more highly polarized than those at any other part of the rod, for the reasons already given (1374) The particles of air situated in sections across these lines of force are least polarized in the sections towards the walls and most polarized in those nearer to the end of the wires (1369) thus, it may well happen, that a particle at the end of the wire is at a tension that will immediately terminate in discharge, whilst in those even only a few inches off, the tension is still beneath that point But suppose the rod to be charged positively, a particle of air A (Pl X Fig 4), next it, being polarized, and having of course its negative force directed towards the rod and its positive force outwards, the instant that discharge takes place between the positive force of the particle of the rod opposite the air and the negative force of the particle of air towards the rod, the whole particle of air becomes positively electrified, and when, the next instant, the discharged part of the rod resumes its positive state by conduction from the surface of metal behind, it not only acts on the particles beyond A, by throwing A into a polarized state again, but A itself, because of its charged state, exerts a distinct inductive act toward these further particles, and the tension is consequently so much exalted between A and B, that discharge takes place there also, as well as again between the metal and A

1435 In addition to this effect, it has been shown that, the act of discharge having once commenced, the whole operation, like a case of unstable equilibrium, is hastened to a conclusion (1370, 1418), the rest of the act being facilitated in its occurrence, and other electricity than that which caused the first necessary tension hurrying to the spot When, therefore, disruptive discharge has once commenced at the root of a brush, the electric force which has been accumulating in the conductor attached to the rod finds a more ready discharge there than elsewhere, and will at once follow the course marked out as it were for it, thus leaving the conductor in a partially discharged state, and the air about the end of the wire in a

[1] *Philosophical Transactions* 1834, pp. 584 585.

the walls of the room, to which its inductive action is directed, is just that time which forms the interval between brush and brush (1420, 1427, 1431, 1447)

1436 The words of this description are long, but there is nothing in the act or the forces on which it depends to prevent the discharge being *instantaneous*, as far as we can estimate and measure it *The consideration of time is*, however, important in several points of view (1418), and in reference to disruptive discharge, it seemed from theory far more probable that

imum intensity

1437 I consider *brush* discharge as probably a successive effect in this way Discharge begins at the root (1426 1553) and extending itself in succession to all parts of the single brush, continues to go on at the root and the previously formed parts until the whole brush is complete, then, by the fall in intensity and

time quite insensible to us

ties and the appearances were such as to make me think an effect of this kind was produced

1439 That the discharge breaks into several ramifications, and by them passes through portions of air alike or nearly alike, as to polarization and the degree of tension the particles there have acquired is a very natural result of the previous state of things and rather to be expected than that the discharge should continue to go straight out into space in a single line amongst those particles which being at a distance from the end of the rod, are in a lower state of tension than those which are near and whilst we cannot but conclude that those parts where the branches of a single brush appear, are more favourably circumstanced for discharge than the darker parts between the ramifications we may also conclude that in those parts where the light of concomitant discharge *is equal there the circumstances are nearly*

ered as taking place into the mass of air around

require any current of the medium in which

towards uninsulated water, a star or glow appeared on the point a current of air passed

water became level

electrified the air in the central dark parts be-

walls of the room &c, and a particle at *a* has polarity of a certain degree of tension, and tends with a certain force to become charged,

[1] *Philosophical Transactions* 1836 pp 686,

particle at *a* is therefore diminished rather than increased The charged particles at *b* and *d* are *now inductive bodies, but* their lines of inductive action are still outwards towards the walls of the room, the direction of the polarity and the tendency of other particles to charge from these, being governed by, or in conformity with, these lines of force

1442 The particles that are charged are *probably very highly charged, but*, the medium being a *non-conductor, they cannot com*municate that state to their neighbours They travel, therefore, under the influence of the repulsive and attractive forces, from the charged conductor towards the nearest uninsulated conductor, or the nearest body in a different *state to themselves, just as charged particles of* dust would travel, and are then discharged, each particle acting, in its course as a centre of inductive force upon any bodies near which it may come The travelling of these charged particles when they are numerous, causes wind and currents, but these will come into consideration under *carrying discharge* (1319, 1562, &c)

1443 When air is said to be electrified, and it frequently assumes this state near electrical machines, it consists, according to my view, of a mixture of electrified and unelectrified particles, the latter being in very large proportion to the former When we gather electricity from air, by a flame or by wires, it is either by the actual discharge of these particles, or by effects dependent on their inductive action, a case of either kind being producible at pleasure That the law of equality between the two forces or forms of force in inductive action is as strictly preserved in these as in other cases, is fully shown by the fact, formerly stated (1173, 1174), that, however strongly air in a vessel might be charged positively, there was an exactly equal amount of negative force on the inner surface of the vessel itself, for no residual portion of either the one or the other electricity could be obtained

1444. I have nowhere said, nor does *it follow*, that the *air is charged only where the luminous* brush appears The charging may extend beyond those parts which are visible, i e, particles to the right or left of the lines of light may receive electricity, the parts which are luminous being so only because much electricity is passing by *them to other parts* (1437) just as in a spark discharge the light is greater as more electricity passes, though it has no necessary relation to the quantity required to commence discharge (1370, 1420) Hence the form we see in a brush may by no means represent the whole quantity of air electrified, for an invisible portion, *clothing the invisible form to* a certain depth, may, at the same time, receive its charge (1552)

1445 Several effects which I have met with in muriatic acid gas tend to make me believe that that gaseous body allows of a dark discharge At the same time, it is *quite clear from theory, that in some gases the reverse of* this may occur, i e., that the charging of the air may not extend even so far as the light We do not know as yet enough of the electric light to be able to state on what it depends, and it is very possible that when electricity bursts forth *into air, all the particles of which are in a state* of tension, light may be evolved by such as being very near to, are not of, those which actually receive a charge at the time

1446 The farther a brush extends in a gas the farther no doubt is the charge or discharge *carried forward*, but this may vary between different gases, and yet the intensity required for the first moment of discharge not vary in the same, but in some other proportion Thus with respect to nitrogen and muriatic acid gases, the former, as far as my experiments *have proceeded, produces far finer and larger brushes* than the latter (1458, 1462), but the intensity required to commence discharge is much higher for the muriatic acid than the nitrogen (1395) Here again, therefore, as in many other qualities, specific *differences are presented by different gaseous dielectrics*, and so prove the special relation of the latter to the act and the phenomena of induction.

1447 To sum up these considerations respecting the character and condition of the brush I may state that it is a spark to air a *diffusion of electric force to matter*, not by conduction, but disruptive discharge, a dilute spark which, passing to very badly conducting matter, frequently discharges but a small portion of the power stored up in the *conductor*, for as the air charged reacts on the *conductor*, whilst the *conductor*, by loss of electricity, sinks in its force (1435), the discharge quickly ceases, until by the dispersion of the charged air and the renewal of the excited *conditions* of the conductor, circumstances *have risen* up to their *first effective condition*, again to cause discharge, and again to fall and rise

1448 The brush and spark gradually pass into one another Making a small ball positive by a good electrical machine with a large prime

conductor, and approaching a large uninsulated discharging ball towards it, very beautiful variations from the spark to the brush may be obtained The drawings of long and powerful sparks, given by Van Marum,[1] Harris and others,[2] also indicate the same phenomena As far as I have observed, whenever the spark has been brushy in air of common pressures the whole of the electricity has not been discharged, but only portions of it, more or less [illegible]

been made to it elsewhere, in the discharging circuit, than where the spark occurred

1449 When an electrical brush from an inch to six inches in length or more is issuing into free air, it has the form given (Pl X, *Fig 3*) But if the hand, a ball, or any knobbed conductor be brought near, the extremities of the coruscations turn towards it and each other, and the whole assumes various forms according to circumstances, as in Pl X, *Figs 5, 6,* and *7* The influence of the circumstances in [illegible]

ramifications illustrate the curved form of the lines of inductive force existing previous to the discharge! for the former are consequences of the latter, and take their course, in each discharge, where the previous inductive tension had been raised to the proper degree They represent these curves just as well as iron filings represent magnetic curves the visible effects in both cases being the consequences of the action of the forces in *the places where* the [illegible]

ured, the bulging form

1450 In reference to the theory of molecular inductive action, I may also add, the proof deducible from the long brushy ramifying spark which may be obtained between a small ball on the positive conductor of an electrical machine, and a larger one at a distance (1448, 1504) What a fine illustration that spark af- [illegible]

tion at a distance in straight lines only, and charge as being electricity retained upon the surface of conductors by the mere pressure of the atmosphere!

1451 When the brush is obtained in rarefied air, the appearances vary greatly, according to circumstances and are exceedingly beautiful Sometimes a brush may be formed of only six or seven branches these being broad and highly luminous, of a purple colour, and in some parts an inch or more apart by a spark discharge at the prime conductor (1455) single brushes may be obtained at pleasure Discharge in the form of a brush is favoured by rarefaction of the air, in the same manner and for the same reason as discharge in the form of a spark (1375), but in every case there is previous induction and charge through the dielectric and polarity of its particles (1437), the induction being as in any other instance, alternately raised by the machine and lowered by the discharge In certain experiments the rarefaction was increased to the utmost degree, and the opposed conducting surfaces brought as near together as possible without producing glow (1529) the [illegible]

high conditions, induction preceded each single brush, and the tense polarized condition of the contiguous particles was a necessary preparation for the discharge itself

1452 The brush form of disruptive discharge may be obtained not only in air and gases, but also in much denser media I procured it in *oil of turpentine* from the end of a wire going through a glass tube into the fluid contained in a metal vessel The brush was small and [illegible]

[1] Description of the Teylerian machine Vol I pp 28, 32 Vol II p 226 &c
[2] *Philosophical Transactions* 1834,

beautifully shown in the brush in air This point may present a little difficulty to those who are not accustomed to see in every discharge an equal exertion of power in opposite directions, a positive brush being considered by such (perhaps in consequence of the common phrase *direction of a current*) as indicating a breaking forth in different directions of the original force, rather than a tendency to convergence and union in one line of passage But the ordinary case of the brush may be compared, for its illustration, with that in which, by holding the knuckle opposite to highly excited glass, a discharge occurs, the ramifications of a brush then leading from the glass and converging into a spark on the knuckle Though a difficult experiment to make, it is possible to obtain discharge between highly excited shellac and the excited glass of a machine when the discharge passes, it is from the nature of the charged bodies, brush at each end and spark in the middle, beautifully illustrating that tendency of discharge to facilitate like action, which I have described in a former page (1418)

1454 The brush has *specific characters* in different gases, indicating a relation to the particles of these bodies even in a stronger degree than the spark (1422, 1423) This effect is in strong contrast with the non variation caused by the use of different substances as *conductors* from which the brushes are to originate Thus, using such bodies as wood, card, charcoal, nitre, citric acid, oxalic acid, oxide of lead, chloride of lead, carbonate of potassa, *potassa fusa*, strong solution of potash, oil of vitriol sulphur, sulphuret of antimony, and hæmatite no variation in the character of the brushes was obtained, except that (dependent upon their effect as better or worse conductors) of causing discharge with more or less readiness and quickness from the machine [1]

1455 The following are a few of the effects I observed in different gases at the positively charged surfaces, and with atmospheres varying in their pressure The general effect of rarefaction was the same for all the gases at first, sparks passed, *these gradually were converted* into brushes, which became larger and more distinct in their ramifications, until, upon further rarefaction, the latter began to collapse and draw in upon each other, *till they formed* a stream across from conductor to conductor then a few lateral streams shot out [illegible] e glass of the vessel [illegible]

[illegible]

[illegible] wire The phenomena [illegible] with the size of the vessel (1477), the degree of rarefaction, and the discharge of electricity from the machine When the latter was in successive sparks, they were most beautiful, the effect of a spark from a small machine being equal to, and often surpassing, that produced by the *constant* discharge of a far more *powerful one*

1456 *Air* Fine positive brushes are easily obtained in air at common pressures and possess the well known purplish light When the air is rarefied the ramifications are very long filling the globe (1477) the light is greatly increased and is of a beautiful purple *colour*, with an occasional rose tint in it

1457 *Oxygen* At common pressures, the brush is very close and compressed, and of a dull whitish colour In rarefied oxygen, the form and appearance are better, the colour somewhat purplish, but all the characters very poor compared to those in air

1458 *Nitrogen* gives brushes with great *facility at the positive surface*, far beyond any other gas I have tried they are almost always fine in form, light, and colour, and in rarefied nitrogen are magnificent They surpass the discharges in any other *gas as to the quantity of* light evolved

1459 *Hydrogen*, at common pressures gave a better brush than oxygen but did not equal nitrogen, the colour was greenish gray *In rarefied* hydrogen, the ramifications were very fine in form and distinctness, but pale in colour, with a soft and velvety appearance, and not at all equal to those in nitrogen In the rarest state of the gas, the colour of the light was a pale gray green

1460 *Coal gas* The brushes were rather difficult to produce, the contrast with nitrogen being great in this respect They were short and strong, generally of a greenish colour, and possessing much of the spark character for, occurring on both the positive and negative terminations, often when there was a dark interval of some length between the two brushes *still the quick, sharp sound* of the spark was produced, as if the discharge had been sudden through this gas, and partaking in that respect, of the character of a spark. In rare coal gas, *the brush forms were better*, but the light very poor and the colour gray

[1] Exception must of course be made of those cases where the root of the brush, becoming a spark, causes a *little diffusion* or even decomposition of the matter there and so gains more or less of a particular colour at that part.

form but weak as to light being of a dull greenish or purplish hue varying with the pressure and other circumstances

1462 *Muriatic acid gas* It is very difficult to

when the interval was about an inch and the discharge, which was still through the gas in

when the intermitting spark current (1455) from the machine was used still I could only with difficulty obtain a brush and that very short though I used rods with rounded terminations (about 0 25 of an inch in diameter)

those in nitrogen

charge to a greater distance than any other gas tried it is also that which constitutes four fifths of our atmosphere and as in atmospheric electrical phenomena one and sometimes both

and through gases is of great interest and if only in reference to atmospheric electricity, deserves extensive and close experimental investigation

tion and its consequences and seems very open to, and accessible by, experimental inquiry

1466 The difference in question used to be expressed in former times by saying that a

air, the positive and negative light upon them differ very little in appearance, and the difference can be observed only upon close examination

1467 The effect varies exceedingly under different circumstances, but, as we must set out from some position, may perhaps be stated thus if a metallic wire with a rounded termination in free air be used to produce the brushy discharge, then the brushes obtained when the wire is charged negatively are very poor and small, by comparison with those produced when the charge is positive Or if a large metal ball connected with the electrical machine be charged *positively*, and a fine uninsulated point be gradually brought towards it, a star appears on the point when at a considerable distance, which, though it becomes brighter, does not change its form of a star until it is close up to the ball whereas, if the ball be charged negatively, the point at a considerable distance has a star on it as before but when brought nearer (in my case to the distance of 1½ inch), a brush formed on it, extending to the negative ball, and when still nearer, (at ⅛ of an inch distance), the brush ceased, and bright sparks passed These variations, I believe, include the whole series of differences and they seem to show at once, that the negative surface tends to retain its discharging character unchanged whilst the positive surface under similar circumstances permits of great variation

1468 There are several points in the character of the negative discharge to air which it is important to observe A metal rod, 0.3 of an inch in diameter, with a rounded end projecting into the air, was charged negatively, and gave a short noisy brush (Pl X, *Fig 8*) It was ascertained both by sight (1427, 1433) and sound (1431) that the successive discharges were very rapid in their recurrence, being seven or eight times more numerous in the same period, than those produced when the rod was charged positively to an equal degree When the rod was positive, it was easy, by working the machine a little quicker, to [illegible] e brush by a glow (1405 [illegible] [illegible] nega[illegible] E[illegible] [illegible], the [illegible] the number of bru[illegible] discharges in a given period, raising at the same time the sound to a higher pitch

1469 A point opposite the negative brush exhibited a star, and as it was approximated caused the size and sound of the negative brush to diminish, and, at last, to cease, leaving the negative end silent and dark, yet effective as to discharge

1470 When the round end of a smaller wire (Pl X, *Fig 9*) was advanced towards the negative brush, it (becoming positive by induction) exhibited the quiet glow at 8 inches distance, the negative brush continuing When nearer, the pitch of the sound of the negative brush rose, indicating quicker intermittence (1431), still nearer, the positive end threw off ramifications and distinct brushes, at the same time, the negative brush contracted in its lateral directions and collected together, giving a peculiar narrow longish brush, in shape like a hair pencil, the two brushes existing at once, but very different in their form and appearance, and especially in the more rapid recurrence of the negative discharges than of the positive On using a smaller positive wire for the same experiment, the glow first appeared on it, and then the brush, the negative brush being affected at the same time, and the two at one distance became exceedingly alike in appearance, and the sounds, I thought, were in unison at all events they were in harmony so that the intermissions of discharge were either isochronous, or a simple ratio existed between the intervals With a higher action of the machine, the wires being retained unaltered the negative surface became dark and silent and a glow appeared on the positive one A still higher action changed the latter into a spark Finer positive wires gave other variations of these effects, the description of which I must not allow myself to go into here

1471 A thinner rod was now connected with the negative conductor in place of the larger one (1468), its termination being gradually diminished to a blunt point, as in Pl X, *Fig 10*, and it was beautiful to observe that, notwithstanding the variation of the brush, the same general order of effects was produced The end gave a small sonorous negative brush, which the approach of the hand or a large conducting surface did not alter, until it was so near as to produce a spark A fine point opposite to it was luminous at a distance being nearer it did not destroy the light and sound of the negative brush, but only tended to have a brush produced on itself, which, at a still less distance passed into a spark joining the two surfaces

1472 When the distinct negative and positive brushes are produced simultaneously in relation to each other in air, the former almost always has a contracted form, as in Pl X, *Fig 11*, very much indeed resembling the for-

which the positive brush itself has when influenced by the lateral vicinity of positive parts acting by induction Thus a brush issuing from a point in the re-entering angle of a pos tive conductor has the same compressed form (Pl X *Fig 12*)

1473 The character of the negative brush is not affected by the chemical nature of the substances of the conductors (1454) but only by their possession of the conducting power in a greater or smaller degree

1474 Rarefaction of common air about a negative ball or blunt point facilitated the de-

negatively to the plate of the air-pump on which the jar containing it stood

1475 A very important variation of the relative forms and conditions of the positive and negative brush takes place on varying the di electric in which they are produced The difference is so very great that it points to a specific relation of this form of discharge to the

1476 In *air* the superiority of the positive brush is well known (1467, 1472) In *nitrogen* it is as great or even greater than in air (1458) In *hydrogen* the positive brush loses a part of

pared to nitrogen (1460) and the positive not much superior to the negative in its character either at common or low pressures In *carbonic acid gas* this approximation of character also occurred In *muriatic acid gas* the positive brush was very little better than the negative and both difficult to produce (1462) as compared with the facility in nitrogen or a r

1477 These experiments were made with rods of brass about a quarter of an inch thick having rounded ends these being opposed in a glass globe 7 inches in diameter containing the

to know the results of a few experiments which are in course of preparation and thinking this Series of *Researches* long enough I shall here close it with the expectation of being able in a few weeks to renew the inquiry and entirely redeem my pledge (1306)

Royal Institution Dec 23 1837

THIRTEENTH SERIES

§ 18 *On Induction (continued)* ¶ ix. *Disruptive Discharge (continued)—Peculiarities of Positive and Negative Discharge either as Spark or Brush—Glow Discharge—Dark Discharge* ¶ x *Convection, or Carrying Discharge* ¶ xi. *Relation of a Vacuum to Electrical Phenomena* § 19 *Nature of the Electrical Current*

RECEIVED FEBRUARY 22, READ MARCH 15, 1838

¶ ix *Disruptive Discharge (continued)*

1480 LET us now direct our attention to the general difference of the positive and negative disruptive discharge, with the object of tracing, as far as possible, the cause of that difference, and whether it depends on the charged conductors principally, or on the interposed dielectric, and as it appears to be great in air and nitrogen (1476), let us observe the phenomena in air first

1481 The general case is best understood by a reference to surfaces of considerable size rather than to points, which involve (as a secondary effect) the formation of currents (1562) My investigation, therefore, was carried on with balls and terminations of different diameters, and the following are some of the principal results

1482 If two balls of very different dimensions, as for instance one-half an inch, and the other three inches in diameter, be arranged at the ends of rods so that either can be electrified by a machine and made to discharge by sparks to the other, which is at the same time uninsulated, then, as is well known, far longer sparks are obtained when the small ball is positive and the large ball negative, than when the small ball is negative and the large ball positive In the former case, the sparks are 10 or 12 inches in length, in the latter, an inch or an inch and a half only

1483 But previous to the description of further experiments, I will mention two words, for which with many others I am indebted to a friend, and which I think it would be expedient to introduce and use It is important in ordinary inductive action, to distinguish at which charged surface the induction originates and is sustained i e , if two or more metallic balls, or other masses of matter, are in inductive relation, to express which are charged originally, and which are brought by them into the opposite electrical condition I propose to call those bodies which are originally charged, *inductric* bodies, and those which assume the opposite state, in consequence of the induction, *inducteous* bodies This distinction is not needful because there is any difference between the sums of the *inductric* and the *inducteous forces*, but principally because, when a ball A is inductric, it not merely brings a ball B, which is opposite to it, into an inducteous state, but also many other surrounding conductors, though some of them may be a considerable distance off, and the consequence is [illegible] not bear the [illegible] when, fir[illegible] inductric [illegible] ball be ma[illegible] the *same state*

1484 Another liberty which I may also occasionally take in language I will explain and limit It is that of calling a particular spark or brush, *positive* or *negative*, according as it may be considered as *originating* at a positive or a negative surface We speak of the brush as positive or negative when it shoots out from surfaces previously in those states, and the experiments of Mr Wheatstone go to prove that it *really begins* at the charged surface, and from thence extends into the air (1437, 1438) or other dielectric According to my view, *sparks* also originate or are determined at one particular spot (1370), namely, that where the tension first rises up to the maximum degree, and when this can be determined as in the simultaneous use of large and small balls, in which case the discharge begins or is determined by the latter, I would call that discharge which passes at *once*, a positive spark, if it was at the positive surface that the maximum intensity was first obtained, or a negative spark, if that necessary

intensity was first obtained at the negative surface

1485 An apparatus was arranged as in Pl XI *Fig 2* A and B were brass balls of very different diameters attached to metal rods moving through sockets on insulating pillars so that the distance between the balls could be varied at pleasure The large ball A 2 inches in diameter was connected with an insulated brass conductor which could be rendered positive or negative directly from a cylinder machine the small ball B 0 25 of an inch in diameter was connected with a discharging train (292) and perfectly uninsulated The brass rods sustaining the balls were 0 2 of an inch in thickness

1486 When the large ball was *positive* and inductric (1483) negative sparks occurred until the interval was 0 49 of an inch then mixed brush and spark between that and 0 51 and from 0 52 and upwards negative brush alone When the large ball was made *negative* and inductric then positive spark alone occurred until the interval was as great as 1 15 inches spark and brush from that up to 1 55 and to have the positive brush alone it required an interval of at least 1 65 inches

1487 The balls A and B were now changed for each other Then making the small ball B inductric *positively* the positive sparks alone continued only up to 0 67 spark and brush occurred from 0 68 up to 0 72 and positive brush alone from 0 74 and upwards Rendering the small ball B inductric and *negative* negative sparks alone occurred up to 0 40 then spark and brush at 0 42 whilst from 0 44 and upwards the noisy negative brush alone took place

1488 We thus find a great difference as the balls are rendered inductric or inducteous the small ball rendered *positive* inducteously giving a spark nearly twice as long as that produced when it was charged positive inductrically and a corresponding difference though not under the circumstances to the same extent was manifest when it was rendered *negative*[1]

1489 Other results are that the small ball rendered positive gives a much longer spark than when it is rendered negative and that the small ball rendered negative gives a brush more readily than when positive in relation to the effect produced by increasing the distance between the two balls

1490 When the interval was below 0 4 of an inch so that the small ball should give sparks whether positive or negative I could not observe that there was any constant difference either in their ready occurrence or the number

as separate negative brushes were far more numerous than the corresponding discharges from it when rendered positive whether those positive discharges were as sparks or brushes

1491 It is therefore evident that when a ball is discharging electricity in the form of brushes the brushes are far more numerous and each contains or carries off far less electric force when the electricity so discharged is negative than when it is positive

1492 In all such experiments as those de-

ductor large so that much power is accumulated quickly for each discharge then the interval is greater at which the sparks are replaced by brushes but the general effect is the same[2]

1493 These results though indicative of very striking and peculiar relations of the electric force or forces do not show the relative

charge as represented Pl XI Fig 3 A and D

[1] For similar experiments on different gases see 1518 —*Dec* 1838

[2] For similar experiments in different gases see 1510–1517 —*Dec.* 1838

PLATE XI

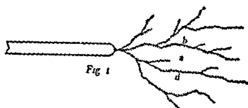


Fig 1

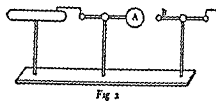


Fig 2

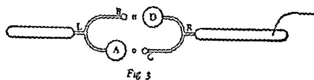


Fig 3

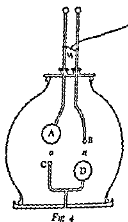


Fig 4

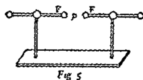
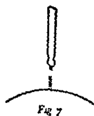


Fig 5


Fig 7

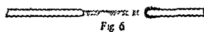
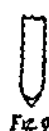
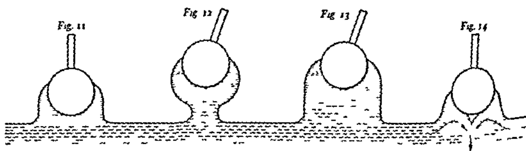

Fig 6


Fig 10



Fig 8


Fig 9


Fig. 11 Fig 12 Fig 13 Fig. 14

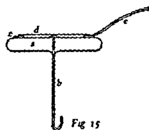


Fig 15

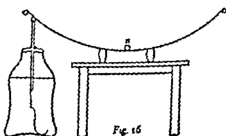


Fig. 16

A and B connected with the same conductor are always charged at once, and that discharge may take place to either of the balls connected with the discharging train, the intervals of discharge *n* and *o* may be properly compared to each other, as respects the influence of large and small balls when charged positively and negatively in air

1494 When the intervals *n* and *o* were each made =0 9 of an inch, and the balls A and B inductric *positively*, the discharge was all at *n* from the small ball of the conductor to the large ball of the discharging train, and mostly by positive brush, though once by a spark When the balls A and B were made inductric *negatively*, the discharge was still from the same small ball, at *n*, by a constant negative brush

1495 I diminished the intervals *n* and *o* to 0 6 of an inch When A and B were inductric *positively*, all the discharge was at *n* as a positive brush when A and B were inductric *negatively*, still all the discharge was at *n*, as a negative brush

1496 [illegible]

in each state, that the discharge might happen at that most favourable to the effect The only difference was that one was in the inductric, and the other in the inducteous state, but whichsoever happened for the time to be in that state, whether positive or negative, had the advantage

1497 [illegible]

about equal at both intervals When, on the [illegible]

in these and similar experiments may very correctly be compared, in their action, to the same balls and ends when electrified in free air at a much greater distance from conductors, than they were in those cases from each other In the first place, the discharge, even when as a spark is, according to my view, determined, and, so to speak, begins at a spot on the surface of the small ball (1374), occurring when the intensity there has risen up to a certain maximum degree (1370), this determination of discharge at a particular spot first, being easily traced from the spark into the brush, by increasing the distance, so as, at last even to render the time evident which is necessary for the production of the effect (1436, 1438) In the next place, the large balls which I have [illegible]

ball rendered either positive or negative is the inductric body

1499 But, as has long been recognised, the small ball is only a blunt end, and, electrically speaking, a point only a small ball so that when a point or blunt end is throwing out its brushes into the air, it is acting exactly as the small balls have acted in the experiments already described, and by virtue of the same properties and relations

1500 It may very properly be said with respect to the experiments, that the large negative ball is as essential to the discharge as the small positive ball, and also that the large negative ball shows as much superiority over the [illegible]

of the dielectric than to the sizes of the conducting balls we may find much importance in such an observation But for the present, [illegible]

1374), that the former, therefore, determine [illegible]

with the other in their influence and actions

1504 The conclusions I arrive at are first, that *when two equal small conducting surfaces* equally placed in air are electrified, one posi- [illegible]

ative brushes already described (1468), the latter set of discharges being found to recur five or six times oftener than the former [1]

1502 If, now, a small ball be made to give brushes or brushy sparks by a powerful machine, we can, in some measure, understand and relate the difference perceived when it is rendered positive or negative It is known to give when positive a much larger and more powerful spark than when negative, and with greater facility (1482) in fact, the spark although it takes away so much more electricity at once commences at a tension higher only in a small degree, if at all On the other hand, if rendered negative though discharge may commence at a lower degree, it continues but for a very short period very little electricity passing away each time These circumstances are directly related for the extent to which the positive spark can reach, and the size and extent of the positive brush, are consequences of the capability which exists of much electricity passing off at one discharge from the positive surface (1468, 1501)

1503 But to refer these effects only to the form and size of the conductor, would according to my notion of induction, be a very imperfect mode of viewing the whole question (1523, 1600) I apprehend that the effects are due altogether to the mode in which the particles of the interposed dielectric polarize, and I have already given some experimental indications of the differences presented by different electrics in this respect (1475, 1476) The modes of polarization as I shall have occasion hereafter to show, may be very diverse in different dielectrics With respect to common air, what seems to be the consequence of a superiority in the positive force at the surface of the small ball, may be due to the more exalted condition of the negative polarity of the particles of air, or of the nitrogen in it (the negative part being, perhaps, more compressed, whilst the positive part is more diffuse, or vice versa [1687, &c]), for such a condition could determine certain effects at the positive ball which would not take place to the same degree at the negative ball, just as well as if the positive ball had possessed some special and independent power of its own

1504 The opinion, that the effects are more likely to be dependent upon the dielectric than the ball, is supported by the character of the two discharges If a small positive ball be throwing off brushes with ramifications ten inches long how can the ball affect that part of a ramification which is five inches from it? Yet the portion beyond that place has the same character as that preceding it, and no doubt has that character impressed by the same general principle and law Looking upon the action of the contiguous particles of a dielectric as fully proved, I see, in such a ramification, a propagation of discharge from particle to particle each doing for the one next it what was done for it by the preceding particle, and what was done for the first particle by the charged metal against which it was situated

1505 With respect to the general condition and relations of the positive and negative brushes in dense or rare air, or in other media and gases if they are produced at different times and places they are of course independent of each other But when they are produced from opposed ends or balls at the same time, in the same vessel of gas (1470, 1477), they are frequently related, and circumstances may be so arranged that they shall be isochronous, occurring in equal numbers in equal times, or shall occur in multiples, i e , with two or three negatives to one positive, or shall alternate, or be quite irregular All these variations I have witnessed, and when it is considered that the air in the vessel, and also the glass of the vessel, can take a momentary charge, it is easy to comprehend their general nature and cause.

1506. Similar experiments to those in air (1485, 1493) were made in different gases, the results of which I will describe as briefly as possible The apparatus is represented Pl XI, Fig 4, consisting of a bell glass eleven inches in diameter at the widest part, and ten and a half inches high up to the bottom of the neck The balls are lettered, as in Pl XI, Fig 3, and are in the same relation to each other, but A and B were on separate sliding wires, which, however, were generally joined by a cross wire, w, above, and that connected with the brass conductor, which received its positive or negative charge from the machine The rods of A and B were graduated at the part moving through the stuffing box, so that the application of a diagonal scale applied there told what was the distance between these balls and those beneath them As to the position of the balls in the jar, and their relation to each other, C and D were three and a quarter inches apart, their

[1] A very excellent mode of examining the relation of small positive and negative surfaces would be by the use of drops of gum water solutions or other liquids. See onwards (1581, 1593)

height above the pump plate five inches, and the distance between any of the balls and the glass of the jar one inch and three-quarters at least,

Another apparatus was occasionally used in connection with that just described, being an open discharger (Pl XI, *Fig 5*), by which a comparison of the discharge in air and that in gases could be obtained The balls E and F, each 0 6 of an inch in diameter, were connected with sliding rods and other balls, and were insulated. When used for comparison, the brass conductor was associated at the same time with the balls A and B of *Figure 4* and ball E of this apparatus (*Fig 5*), whilst the balls C, D and F were connected with the discharging train

1507 I will first tabulate the results as to the

those at the interval p in the air, between E and F (*Fig 5*) The table sufficiently explains itself It will be understood that all discharge was in the air, when the interval there was less than that expressed in the first or third columns of figures, and all the discharge in the gas, when the *interval in air* was greater than that in the second or fourth column of figures At intermediate distances the discharge was occasionally at both places, i e, sometimes in the air, sometimes in the gas

Constant interval n between B and D = 1 inch	Interval p in parts of an inch			
	When the small ball B was inductric and *positive* the discharge was all at p in air before	at n in the gas after	When the small ball B was inductric and *negative* the discharge was all at p in air before	at n in the gas after
	$p =$	$p =$	$p =$	$p =$
In Air	0 40	0 50	0 28	0 33
In Nitrogen	0 30	0 65	0 31	0 40
In Oxygen	0 33	0 52	0 27	0 30
In Hydrogen	0.20	0 40	0 22	0 24
In Coal gas	0 20	0 90	0.20	0.27
In Carbonic acid	0 64	1 30	0.30	0 45

1508 These results are the same generally,

conductor in the conveyance and derangement of that charge Another cause of difference in *the ratios is, no doubt, the relative sizes of the* discharge balls in air, in the former case they were of very different size, here they were alike

1509 In future experiments intended to have the character of accuracy, the influence of

not of glass

1510 The next set of results are those obtained when the intervals n and o (Pl XI, *Fig 4*) were made equal to each other, and relate to the greater facility of discharge at the small ball, when rendered positive or negative (1493)

1511 In *air*, with the intervals = 0 4 of an inch, A and B being inductric and positive, discharge was nearly equal at n and o, when A and B were inductric and negative, the discharge was mostly at n by negative brush

facility than the positive

1512 *Nitrogen* Intervals n and o = 0 4 of an inch A, B inductric positive discharge at both intervals, most at n, by positive sparks, A, B

most ready discharge

o by negative brush So here the negative small

seems most facile.

1515 *Coal gas* n and o=0 4 of an inch A, B inductric positive, discharge nearly all at o by negative spark A, B inductric negative, discharge nearly all at n by negative spark Intervals=0 8 of an inch, and A, B inductric positive, discharge mostly at o by negative brush A, B inductric negative, discharge all at n by negative brush Here the negative discharge most facile

1516 *Carbonic acid gas* n and o=0 4 of an inch A, B inductric positive, discharge nearly all at o, or negative A, B inductric negative, discharge nearly all at n or negative Intervals=0 8 of an inch A, B inductric positive, discharge mostly at o, or negative A, B inductric negative, discharge all at n, or negative In this case the negative had a decided advantage in facility of discharge

1517 Thus, if we may trust this form of experiment, the negative small ball has a decided advantage in facilitating disruptive discharge over the positive small ball in some gases, as in carbonic acid gas and coal gas (1399), whilst in others that conclusion seems more doubtful and in others, again there seems a probability that the positive small ball may be superior All these results were obtained at very nearly the same pressure of the atmosphere

1518 I made some experiments in these gases whilst in the air jar (Pl XI, *Fig 4*), as to the change from spark to brush, analogous to those in the open air already described (1486, 1487) I will give, in a table, the results as to when brush began to appear mingled with the spark, but the after results were so varied, and the nature of the discharge in different gases so different, that to insert the results obtained without further investigation, would be of little use At intervals less than those expressed the discharge was always by spark

	Discharge between balls B and D		Discharge between balls A and C	
	Small ball B inductric pos	Small ball B inductric neg	Large ball A inductric pos	Large ball A inductric neg
Air	0.55	0 30	0 40	0 75
Nitrogen	0 30	0 40	0 52	0 41
Oxygen	0 70	0.30	0 45	0 82
Hydrogen	0 20	0 10		
Coal gas	0 13	0 30	0 30	0 14
Carbonic acid	0 82	0 43	1 60	above 1 80, had not space

1519 It is to be understood that sparks occurred at much higher intervals than these, the table only expresses that distance beneath which all discharge was as spark Some curious relations of the different gases to discharge are already discernible, but it would be useless to consider them until illustrated by further experiments

1520 I ought not to omit noticing here, that Professor Belli of Milan has published a very valuable set of experiments on the relative dissipation of positive and negative electricity in the air,[1] he finds the latter far more ready, in this respect, than the former.

1521 I made some experiments of a similar kind, but with sustained high charges, the results were less striking than those of Signore Belli, and I did not consider them as satisfactory I may be allowed to mention in connexion with the subject, an interfering effect which embarrassed me for a long time When I threw positive electricity from a given point into the air, a certain intensity was indicated by an electrometer on the conductor connected with the point, but as the operation continued this intensity rose several degrees then making the conductor negative with the same point attached to it, and all other things remaining the same, a certain degree of tension was observed in the first instance, which also gradually rose as the operation proceeded Returning the conductor to the positive state, the tension was at first low, but rose as before, and so also when again made negative

1522 This result appeared to indicate that the point which had been giving off one electricity was, by that, more fitted for a short time to give off the other But on closer examination I found the whole depended upon the inductive reaction of that air, which being charged by the point, and gradually increasing in quantity before it, as the positive or negative issue was continued, diverted and removed a part of the inductive action of the surrounding wall, and thus apparently affected the powers of the point, whilst really it was the dielectric itself that was causing the change of tension.

1523 The results connected with the different conditions of positive and negative discharge will have a far greater influence on the philosophy of electrical science than we at present imagine, especially if, as I believe, they depend on the peculiarity and degree of polarized

[1] *Bibliothèque Universelle* 1836 September p 152.

condition which the molecules of the dielectrics concerned acquire (1503, 1600) Thus, for instance, the relation of our atmosphere and the earth within it, to the occurrence of spark or brush, must be especial and not accidental (1464) It would not else consist with other meteorological phenomena, also of course dependent on the special properties of the air, and which being themselves in harmony the most perfect with the functions of animal and vegetable life, are yet restricted in their actions, not by loose regulations, but by laws the most precise

1524 Even in the passage through air of the voltaic current we see the peculiarities of posi-

[illegible]

when a zinc and a copper ball, the same in size, were placed respectively in copper and zinc spheres also the same in size, and excited by electrolytes or dielectrics of the same strength and nature, the zinc ball far surpassed the zinc sphere in action, may also be connected with these phenomena for it is not difficult to conceive how the polarity of the particles shall be affected by the circumstance of the positive surface, namely the zinc, being the larger or the smaller of the two inclosing the electrolyte It is even possible, that with different electrolytes or dielectrics the ratio may be considerably varied, or in some cases even inverted

Glow Discharge

1526 That form of disruptive discharge which appears as a *glow* (1359, 1405), is very peculiar and beautiful it seems to depend on a quick and almost continuous charging of the air close to, and in contact with the conductor

1527 *Diminution of the charging surface* will produce it Thus, when a rod 0 3 of an inch in diameter, with a rounded termination, was ren-

[illegible]

and also with blunt conical points, it occurred still more readily, and with a fine point I could not obtain the brush in free air, but only this glow The positive glow and the positive star are, in fact, the same

1528 *Increase of power in the machine* tends to produce the glow, for rounded terminations which will give only brushes when the machine is in weak action, will readily give the glow when it is in good order

1529 *Rarefaction of the air* wonderfully fa-

[illegible]

appeared flexible, and revolved [illegible] paratively slow motion, i e, about [illegible] times in a second This ring [illegible] tion are beautifully connected [illegible] chanical currents (1576) tak[illegible] the receiver These glows in [illegible]

[illegible]

mon pressures is difficult. I [illegible] on the rod 0 3 of an inch [illegible] machine, nor on much [illegible] questionable as yet, whe[illegible] what is called the negat[illegible] duced and minute but [illegible] or a glow similar to the [illegible] point [illegible]ith

1531 In rarefied [illegible]gh, easily be obtained. I [illegible]ne metal rods, about [illegible]it are introduced [illegible]re being rarefied), [illegible] other, are abo[illegible] can be obtai[illegible] only the end[illegible] behind On [illegible] adjusting the [illegible]

tive ball could be covered with glow, whether it were the inductric or the inducteous surface

1532 When rods are used it is necessary to be aware that, if placed concentrically in the jar or globe, the light on one rod is often reflected by the sides of the vessel on to the other rod, and makes it apparently luminous, when really it is not so This effect may be detected by shifting the eye at the time of observation, or avoided by using blackened rods

1533 It is curious to observe the relation of *glow*, *brush*, and *spark* to each other, as produced by positive or negative surfaces, thus, beginning with spark discharge, it passes into brush much sooner when the surface at which the discharge commences (1484) is negative, than it does when positive, but proceeding onwards *in the order of change, we find that the* positive brush passes into *glow* long before the negative brush does So that, though each presents the three conditions in the same general order, the series are not precisely the same It is probable, that, when these points are minutely examined, as they must be shortly, we shall find that each different gas or dielectric presents its own peculiar results, dependent upon the mode in which its particles assume polar electric condition

1534 *The glow occurs in all gases in which* I have looked for it These are air, nitrogen, oxygen, hydrogen, coal gas, carbonic acid, muriatic acid, sulphurous acid and ammonia I thought also that I obtained it in oil of turpentine, but if so it was very dull and small

1535 The glow is always accompanied by a wind proceeding either directly out from the glowing part, or directly towards it, the former being the most general case This takes place even when the glow occurs upon a ball of considerable size and *if matters be so arranged* that the ready and regular access of air to a part exhibiting the glow be interfered with or prevented, *the glow then disappears*

1536 I have never been able to analyse or separate the glow into visible elementary intermitting discharges (1427, 1433), nor to obtain the other evidence of intermitting action, namely an audible sound (1431) The want of success, as respects trials made by ocular means, may depend upon the large size of the glow preventing the separation of the visible images and, indeed, if it does intermit, it is not likely that all parts intermit at once with a simultaneous *regularity*.

1537. All the effects tend to show, that *glow* is due to a continuous charge or discharge of air, in the former case being accompanied by a current from, and in the latter by one to, the place of the glow As the surrounding air comes up to the charged conductor, on attaining that spot at which the tension of the particles is raised to the sufficient degree (1370, 1410), it becomes *charged, and then moves off,* by the joint action of the forces to which it is subject, and, at the same time that it makes way for other particles to come and be charged in turn, actually helps to form that current by which they are brought into the necessary position Thus, through the regularity of the forces a constant and quiet result is produced, and that result is, the charging of successive portions of air, the production of a current, and of a continuous glow

1538 *I have frequently been able to* make the termination of a rod, which, when left to itself, would produce a brush, produce in preference a glow, simply by aiding the *formation* of a current of air at its extremity, and, on the other hand, it is not at all difficult to convert the glow into brushes, by affecting the current of air (1574, 1579) or the inductive action near it

1539 The transition from glow, on the one hand, to brush and spark, on the other, and, *therefore, their connexion, may be* established in various ways Those circumstances which tend to facilitate the charge of the air by the excited conductor, and also *those which tend* to keep the tension at the same degree notwithstanding the discharge, assist in producing the glow, whereas those which tend *to resist the* charge of the air or other dielectric, and those which favour the accumulation of electric force prior to discharge, which, sinking by that act, has to be exalted before the tension can again acquire the requisite degree, favour intermitting discharge, and, therefore, the production of brush or spark. Thus, rarefaction of the air, *the removal of large conducting surfaces from* the neighbourhood of the glowing termination, the presentation of a sharp point towards it, help to sustain or produce the *glow* but the condensation of the air, the presentation of the hand or other large surface, the gradual approximation of a discharging *ball, tend to convert* the glow into brush or even spark. All these circumstances may be traced and reduced, in a manner easily comprehensible, to their relative power of assisting to produce, either a *continuous* discharge to the air, which gives the glow; or an *interrupted* one, which produces the brush, and, in a more exalted condition, the spark.

1540 The rounded end of a brass rod 0 3 of *an inch in diameter was covered with a posi* tive glow by the working of an electrical ma chine on stopping the machine so that the charge of the connected conductor should fall the glow changed for a moment into brushes

approach of the hand caused the glow to con tract at the very end of the wire then to throw out a luminous point which becoming a foot stalk (1426) finally produced brushes with large ramifications All these results are in accord ance with what is stated above *(1539)*

1541 Greasing the end of a rounded wire will immediately make it produce brushes in stead of glow A ball having a blunt point which can be made to project more or less beyond its surface at pleasure can be made to produce every gradation from glow through brush to spark

1542 It is also very interesting and instructive to trace the transition from spark to glow, through the intermediate condition of stream between ends in a vessel containing air more or less rarefied but I fear to be prolix

1543 All the effects show that the glow is in its nature exactly the same as the luminous part of a brush or ramification namely a charg ing of air, the only difference being that the glow has a continuous appearance from the constant renewal of the same action in the *same place whereas the ramification is due to* a momentary independent and intermitting action of the same kind

Dark Discharge

1544 I will now notice a very remarkable circumstance in the luminous discharge accom

that was continued the ends were separated from each other At the moment of separation a continuous glow came over the end of the *negative rod* the positive termination remain ing quite dark As the distance was increased a purple stream or haze appeared on the end of the positive rod and proceeded directly outwards towards the negative rod elongating as the interval was enlarged but never joining the negative glow there being always a short dark space between This space of about 1/16th or 1/20th of an inch was apparently invariable in its extent and its position relative to the negative rod nor did the negative glow vary Whether the negative end where inductric or inducteous the same effect was produced It was strange to see the positive purple haze diminish or lengthen as the ends were sepa rated and yet this dark space and the negative glow remain unaltered (Pl XI *Fig 6*)

1545 Two balls were then used in a large air pump receiver and the air rarefied The usual transitions in the character of the dis charge took place but whenever the luminous stream which appears after the spark and the brush have ceased was itself changed into glow at the balls the dark space occurred and that whether the one or the other ball was made in ductric or positive or negative

dark space but this was a deception arising from the overlapping of the convex termina tion of the negative glow and the concave termination of the positive stream More careful observation and experiment have convinced me that when the negative glow occurs it never visibly touches the luminous part of the positive discharge but that the dark space is always there

1547 This singular separation of the posi tive and negative discharge as far as concerns

[1] See Professor Johnson s experiments *Silliman s Journal* XXV p 57

taking place across the dark part of the dielectric to an extent quite equal to what occurs in the luminous part This difference in the result would seem to imply a distinction in the modes by which the two electric forces are brought into equal

accurately in what the d

ing luminous, and the inquiry is important, because it is connected with that degree of tension which is necessary to originate discharge (1368, 1370)

are also common enough but these are not

2) but, in place of connecting the inducteous

chine, it was found that whenever sonorous and luminous discharge occurred at the balls A B, the jar became charged, but that when these did not occur, the jar acquired no charge and such was the case when small rounded terminations were used in place of the balls, and also in whatever manner they were arranged Under these circumstances, therefore, discharge even between the air and conductors was always luminous

1550 But in other cases, the phenomena are such as to make it almost certain that dark discharge can take place across air If the rounded end of a metal rod, 0 15 of an inch in diameter,

negative surfaces, it seems a reasonable conclusion that the charged portions meet somewhere in the interval, and there discharge to each other, without producing any luminous phenomena It is possible, however, that the air electrified positively at the glowing end

dark discharge need not, of necessity, occur But I incline to the former opinion, and think, that the diminution in size of the negative brush, as the positive glow comes on to the end of the opposed wire, is in favour of that view

1551 Using rarefied air as the dielectric, it is very easy to obtain luminous phenomena as brushes, or glow, upon both conducting balls or terminations, whilst the interval is dark, and that, when the action is so momentary that I think we cannot consider currents as effecting discharge across the dark part Thus if two balls, about an inch in diameter, and 4 or more inches apart, have the air rarefied about them, and are then interposed in the course of discharge, an interrupted or spark current being produced at the machine,[1] each termination may be made to show luminous phenomena, whilst more or less of the interval is quite dark The discharge will pass as suddenly as a re-

dark part as true disruptive discharge, and not by convection

1552 Hence I conclude that dark disruptive discharge may occur (1547, 1550), and also, that, in the luminous brush, the visible ramifications may not show the full extent of the

such things as dark discharges analogous in form to the brush and the spark, but not luminous in any part (1445)

So to speak, the discharge begins in darkness and the light is a mere consequence of the

quantity which, after discharge has commenced, flows to that spot and there finds its most fa

in oxygen of the discharge from spark to brush *(1518), every spark was immediately preceded* by a short brush

terminations (1544) (Pl XI, *Fig 6*), were placed in *muriatic acid gas* (1445, 1463) at the pressure

were replaced by squat brushy intermitting glows upon both terminations, with a dark part between When the current at the ma

sharp spark and with a still larger interval, produced a feeble brush on the inductric posi-

very sudden dark parts would occur next to the brightest portions of the spark Again with these ends and also with balls (1422), the bright sparks would be sometimes red, sometimes

panied by a sharp snapping noise, as if quick in its occurrence

1558 *Hydrogen* frequently gave peculiar sparks one part being bright red whilst the *other was a dull pale gray, or else the whole* spark was dull and peculiar

(Pl XI, *Fig 7*) The posi

(1544) When by any circumstance a bright spark was determined, the contrast with the peculiar spark described was very striking for it always had a faint purple part, but the place of this part was constantly near the positive ball

mation [1]

1561 What I have had to say regarding dis

[1] I cannot resist referring here by a note to B ot a philosophical view of the nature of the light of the electric discharge *Annales de Chimie* LIII

of a query, whether we have not reason to consider the *tension or retention* and *after discharge* in air or other insulating dielectrics, as the same thing with *retardation* and *discharge* in a metal wire, differing only, but almost infinitely, in degree (1334, 1336) In other words, can we not, by a *gradual chain of association*, carry up discharge from its occurrence in air, through spermaceti and water, to solutions, *and then on to chlorides, oxides and metals*, without any essential change in its character, *and*, at the same time connecting the insensible conduction of air, through muriatic acid gas and the dark discharge, with the better conduction *of spermaceti* water, and the all but perfect conduction of the metals, associate the phenomena at both extremes? and may it not be, that the retardation and ignition of a wire are effects exactly correspondent in their nature to the retention of charge and spark in air? If so, here again the two extremes in property amongst dielectrics will be found to be in intimate relation the whole difference probably depending upon the mode and degree in which their particles polarize under the influence of inductive actions (1338, 1603, 1610)

¶ x *Convection, or Carrying Discharge*

1562 The last kind of discharge which I have *to consider* is that *effected by the motion* of charged particles from place to place It is apparently very different in its nature to any of the former modes of discharge (1319), but, as the result is the same, may be of great importance *in illustrating, not merely the nature* of discharge itself, but also of what we call the electric current *It often*, as before observed, in cases of brush and glow (1440, 1535), joins its effect to that of disruptive discharge, to complete the act *of neutralization* amongst the electric forces

1563 The particles which being charged, then travel, may be either of insulating or conducting matter, large or small The consideration in the first place of a large particle of conducting matter may perhaps help our conceptions

1564 *A copper boiler 3 feet in diameter was* insulated and electrified but so feebly that dissipation by brushes or disruptive discharge did not occur at its edges or projecting parts in a sensible degree A brass ball 2 [illegible] ameter [illegible] was [illegible] surface of the boiler, at such distance (two inches more or less) as not to receive any direct charge from it, it became itself charged, although insulated the whole time, and its electricity was the *reverse* of that of the boiler

1565 *This effect was the strongest opposite* the edges and projecting parts of the boiler, and weaker opposite the sides, or those extended portions of the *surface* which, *according* to Coulomb's results, have the weakest charge *It was very strong opposite a rod projecting a* little way from the boiler It occurred when the copper was charged negatively as well as positively it *was produced* also with *small* balls down to 0 2 of an inch and less in diameter, *and also with smaller charged conductors than* the copper It is, indeed, hardly possible in some cases to carry an insulated ball within an inch or two of a charged plane *or convex* surface without its receiving a charge of the contrary kind to that *of the surface.*

1566 This effect is one of induction between the bodies, not of communication *The ball, when related to the positive charged surface* by the intervening dielectric, has its opposite sides brought into contrary states, that side towards the boiler being negative and the outer side positive More inductric action is *directed towards* it than would have *passed* across the same place if the ball had not been there *for several reasons* amongst others because, being a conductor, the resistance of the particles of the dielectric, which otherwise *would have* been there, is removed (1298) and also, because the reacting positive surface of *the ball* being *projected farther out from* the boiler than when there is no introduction of conducting matter, is more free therefore *to act through* the rest of the dielectric towards surrounding conductors, and so favours *the exaltation of* that inductric polarity which is directed in its course It is, as to the exaltation of *force upon* its outer surface beyond *that upon the* inductric surface of the boiler, as if *the latter were* itself protuberant *in that direction* Thus it acquires a state like, but higher than, that *of the* surface of the boiler which *causes it*, and sufficiently exalted to discharge at its positive surface to the air, or to affect small *particles, as it is itself affected* by the boiler, and *they flying* to it, take a charge and pass off, *and so the* ball, *as a whole, is* brought into the contrary inducteous state The consequence is that if free to move, its tendency, under *the influence of all the forces*, to approach the boiler is increased, whilst it at the same *time becomes* more and *more* exalted in its condition, both of

polarity and charge, until, at a certain distance, discharge takes place, it acquires the same state as the boiler, is repelled, and passing to that conductor most favourably circumstanced to discharge it, there resumes its first indifferent condition

1567 It seems to me, that the manner in [illegible]

ductric body cannot give off its electricity to the air, the inducteous body *can* effect the discharge of the same kind of force, is curious, *and, in the case of elongated or irregularly* shaped conductors, such as filaments or particles of dust, the effect will often be very ready, and the consequent attraction immediate

1568 The effect described is also probably influential in causing those variations in spark discharge referred to in the last series (1386, 1390, 1391) for if a particle of dust were drawn towards the axis of induction between the balls, it would tend, whilst at some distance from that axis, to commence discharge at itself, in the manner described (1566), and that commencement might so far facilitate the act (1417, 1420) as to make the complete discharge, as spark, pass through the particle, though it might not be the shortest course from ball to ball. So also, with equal balls at equal distances, as in the experiments of comparison already described (1493, 1506), a particle being between one pair of balls would cause discharge there in preference; or even if a particle were between each, difference of size or shape would give one for the time a predominance over the other.

1569 The power of particles of dust to carry off electricity in cases of high tension is well known, and I have already mentioned some instances of the kind in the use of the inductive [illegible]

the smoke of a glowing green wax taper, which, presenting a successive stream of such particles, makes their course visible [illegible]

the place of carriers, and their progressive action is exceedingly interesting

1571. A very striking effect was produced on oil of turpentine, which, whether it was due to the carrying power of the particles in it, or to any other action of them, is perhaps as yet doubtful A portion of that fluid in a glass vessel had a large uninsulated silver dish at the bottom, and an electrified metal rod with a round termination dipping into it at the top The insulation was very good, and the attraction and other phenomena striking The rod [illegible]

commingled with a pint of the dielectric, the latter had lost by far the greatest portion of its insulating power, no sparks could be obtained in the fluid, and all the phenomena dependent [illegible]

The water, therefore, was merely diffused through the oil of turpentine, not combined with or dissolved in it but whether the minute particles acted as carriers, or whether they [illegible]

ing power, as compared with the oil of turpentine, is as yet questionable

1572 The analogy between the action of [illegible]

spot where these inductric forces are most easily compensated by the contrary inducteous forces.

1573 Why a point should be so exceedingly favourable to the production of currents in a fluid insulating dielectric, as air, is very evident It is at the extremity of the point the intensity necessary to charge the air is [illegible]

acquired (1374), it is from thence that the charged particle recedes, and the mechanical force which it impresses on the air to form a current is in every way favoured by the shape and position of the rod, of which the point forms the termination At the same time, the point, having become the origin of an active mechanical force, does by the very act of causing that force, namely, by discharge, prevent any other part of the rod from acquiring the same necessary condition and so preserves and sustains its own predominance

1574 The very varied and beautiful phenomena produced by sheltering or enclosing the point, illustrate the production of the current exceedingly well, and justify the same conclusions, it being remembered that in such cases the effect upon the discharge is of two kinds For the current may be interfered with by stopping the access of fresh uncharged air, or retarding the removal of that which has been charged, as when a point is electrified in a tube of insulating matter closed at one extremity, or the electric condition of the point itself may be altered by the relation of other parts in its neighbourhood, also rendered electric, as when the point is in a metal tube, by the metal itself, or when it is in the glass tube by a similar action of the charged parts of the glass, or even by the surrounding air which has been charged, and which cannot escape

1575 Whenever it is intended to observe such inductive phenomena in a fluid dielectric as have a direct relation to, and dependence upon, the fluidity of the medium such, for instance, as discharge from points, or attractions and repulsions &c, then the mass of the fluid should be great and in such proportion to the distance between the inductric and inducteous surfaces as to include all the lines of inductive force (1369) between them otherwise, the effects of currents, attraction, &c which are the resultants of all these forces cannot be obtained The phenomena which occur in the open air, or in the middle of a globe filled with oil of turpentine, will not take place in the same media if confined in tubes of glass, shellac, sulphur, or other such substances, though they be excellent insulating dielectrics nor can they be expected for in such cases the polar forces, instead of being all dispersed amongst fluid particles which tend to move under their influence, are now associated in many parts with particles that, notwithstanding their tendency to motion, are constrained by their solidity to remain quiescent.

1576 The varied circumstances under which, with conductors differently formed and constituted, currents can occur, all illustrate the same simplicity of production A ball if the intensity be raised sufficiently on its surface and that intensity be greatest on a part consistent with the production of a current of air up to and off from it will produce the effect like a point (1537), such is the case whenever the glow occurs upon a ball, the current being essential to that phenomenon If as large a sphere as can well be employed with the production of glow be used, the glow will appear at the place where the current leaves the ball, and that will be the part directly opposite to the connection of the ball and rod which supports it but by increasing the tension elsewhere, so as to raise it above the tension upon that spot, which can easily be effected inductively, then the place of the glow and the direction of the current will also change, and pass to that spot which for the time is most favourable for their production (1591)

1577 For instance, approaching the hand towards the ball will tend to cause brush (1539), but by increasing the supply of electricity the condition of glow may be preserved, then on moving the hand about from side to side the position of the glow will very evidently move with it

1578 A point brought towards a glowing ball would at twelve or fourteen inches distance make the glow break into brush but when still nearer, glow was reproduced, probably dependent upon the discharge of wind or air passing from the point to the ball, and this glow was very obedient to the motion of the point, following it in every direction

1579 Even a current of wind could affect the place of the glow, for a varnished glass tube being directed sideways towards the ball, air was sometimes blown through it at the ball and sometimes not In the former case, the place of the glow was changed a little, as if it were blown away by the current, and this is just the result which might have been anticipated All these effects illustrate beautifully the general causes and relations, both of the glow and the current of air accompanying it (1574)

1580 Flame facilitates the production of a current in the dielectric surrounding it Thus, if a ball which would not occasion a current in the air have a flame, whether large or small formed on its surface, the current is produced with the greatest ease, but not the least difficulty can occur in comprehending the effective

action of the flame in this case, if its relation *as part of the surrounding dielectric, to the* electrified ball, be but for a moment considered (1375, 1380)

1581 Conducting fluid terminations, instead of rigid points, illustrate in a very beautiful manner the formation of the currents, with their effects and influence in exalting the conditions under which they were commenced Let the rounded end of a brass rod, 0 3 of an inch or thereabouts in diameter, point downwards in free air, let it be amalgamated, and have a drop of mercury suspended from it, and then let it be powerfully electrized The mercury will present the phenomenon of *glow*, a current of air will rush along the rod, and set off from the mercury directly downwards and

from this spot The change is from the form of *a* (Pl *XI*, *Fig 8*) to that of *b*, and is due almost, if not entirely, to the mechanical force of the current of air sweeping over its surface

1582 As a comparative observation, let it be noticed that a ball gradually brought towards it converts the glow into brushes, and ultimately sparks pass from the most projecting part of the mercury A point does the same, but at much smaller distances

remain, forming a conical drop (Pl XI, *Fig 9*), accompanied by a strong current If glow be produced, the drop will be smooth on the surface If a short low brush is formed, a minute tremulous motion of the liquid will be visible but both effects coincide with the principal one to be observed, namely the regular

this fluid

1584 With a drop of water, the effects were of the same kind, and were best obtained when a portion of gum water or of syrup hung from a ball (Pl XI, *Fig 10*) When the machine was worked slowly, a fine large quiet conical drop, with concavelateral outline, and a small rounded *end was produced on* which the glow appeared, whilst a steady wind issued in a direction from the point of the cone, of sufficient force to depress the surface of uninsulated water held opposite to the termination When the machine was worked more rapidly some of the water was driven off, the smaller pointed portion

brush discharge was heard, and the vibrations of the water and the successive discharges of the individual brushes were simultaneous When water from beneath was brought towards the drop, it did not indicate the same regular strong contracted current of air as before, and when the distance was such that sparks passed, the water beneath was *attracted* rather than driven

always from the metal of the rod, over the surface of the water, to the point, and then across the air to the ball This is a natural consequence of the deficient conducting power of the fluid (1584 1585)

1586 Why the drop vibrated, changing its form between the periods of discharging brushes, so as to be more or less acute at particular instants, to be most acute when the brush issued forth, and to be isochronous in its action, and

formation of the carrying current of air, and the manner in which it exhibits its existence and influence by giving form to the drop

1587 That the drop, when of water, or a better conductor than water, is formed into a cone principally by the current of air, is shown

and was replaced by one from the point beneath, which, *if the latter were held near enough* to the drop, actually blew it aside, and rendered it concave in form.

1588 It is hardly necessary to say what happened with still worse conductors than water, as oil, or oil of turpentine, the fluid itself was then spun out into threads and carried off, not only because the air rushing over its surface helped to sweep it away, but also because its insulating particles assumed the same charged state as the particles of air, and, not being able to discharge to them in a much greater degree than the air particles themselves could do, were carried off by the same causes which urged these in their course A similar effect with melted sealing wax on a metal point forms an old and well-known experiment

1589 A drop of gum water in the exhausted receiver of the air pump was not sensibly affected in its form when electrified When air was let in, it began to show change of shape when the pressure was ten inches of mercury At the pressure of fourteen or fifteen inches the change was more sensible and as the air increased in density the effects increased, until they were the same as those in the open atmosphere The diminished effect in the rare air I refer to the relative diminished energy of its current, that diminution depending, in the first place, on the lower electric condition of the electrified ball in the rarefied medium and in the next, on the attenuated condition of the dielectric, the cohesive force of water in relation to rarefied air being something like that of mercury to dense air (1581), whilst that of water in dense air may be compared to that of mercury in oil of turpentine (1597)

1590 When a ball is covered with a thick conducting fluid, as treacle or syrup it is easy by inductive action to determine the wind from almost any part of it (1577), the experiment, which before was of rather difficult performance, being rendered facile in consequence of the fluid enabling that part, which at first was feeble in its action, to rise into an exalted condition by assuming a pointed form

1591 To produce the current, the electric intensity must rise and continue at *one spot*, namely at the origin of the current, higher than elsewhere, and then, air having a uniform and ready access, the current is produced If no current be allowed (1574), then discharge may take place by brush or spark. But whether it be by brush or spark, or wind, it seems very probable that the initial intensity or tension at which a particle of a given gaseous dielectric charges, or commences discharge, is, under the conditions before expressed, always the same (1410).

1592 It is not supposed that all the air which enters into motion is electrified, on the contrary, much that is not charged is carried on into the stream The part which is really charged may be but a small proportion of that which is ultimately set in motion (1442)

1593 When a drop of gum water (1584) is made *negative*, it presents a larger cone than when made positive, less of the fluid is thrown off, and yet, when a ball is approached, sparks can hardly be obtained, so pointed is the cone and so free the discharge A point held opposite to it did not cause the retraction of the cone to such an extent as when it was positive All the effects are so different from those presented by the positive cone that I have no doubt such drops would present a very instructive method of investigating the difference of positive and negative discharge in air and other dielectrics (1480 1501)

1594 That I may not be misunderstood (1587), I must observe here that I do not consider the cones produced as the result *only* of the current of air or other insulating dielectric over their surface When the drop is of badly conducting matter, a part of the effect is due to the electrified state of the particles, and this part constitutes almost the whole when the matter is melted sealing wax, oil of turpentine, and similar insulating bodies (1588) But even when the drop is of good conducting matter, as water, solutions, or mercury, though the effect above spoken of will then be insensible (1607), still it is not the mere current of air or other dielectric which produces all the change of form, for a part is due to those attractive forces by which the charged drop, if free to move, would travel along the line of strongest induction, and not being free to move, has its form elongated until the *sum* of the different forces tending to produce this form is balanced by the cohesive attraction of the fluid The effect of the attractive forces are well shown when treacle, gum water, or syrup is used for the long threads which spin out, at the same time that they form the axes of the currents of air, which may still be considered as determined at their points, are like flexible conductors, and shew by their directions in what way the attractive forces draw them

1595 When the phenomena of currents are observed in dense insulating dielectrics they present us with extraordinary degrees of mechanical force Thus if a pint of well rectified and filtered (1571) oil of turpentine be put into a glass vessel, and two wires be dipped into it

duced they cling about the conductors but

into violent motion throughout its whole mass whilst at the same time it will rise two three or four inches up the machine wire and dart off in jets from it into the air

1596 If very clean uninsulated mercury be at the bottom of the fluid and the wire from the machine be terminated either by a ball or a

observed and will be seen to rush down the wire proceeding directly from it towards the

enter upon their course

very pointed and even particles of the metal could be spun out and carried off by the currents of the dielectric The form of the liquid metal was *just like that of the syrup in air* (1584) the point of the cone being quite as

tric

1598 If the mercury at the bottom of the fluid be connected with the electrical machine whilst a rod is held in the hand terminating in a ball three quarters of an inch less or more

come more bulky and may then also be raised *higher assuming the form (Fig 13)* and all the time that these effects continue currents and counter-currents sometimes running very close together may be observed in the raised column of fluid

1599 It is very difficult to decide by sight the direction of the currents in such experiments as these If particles of silk are intro-

on the mercury beneath the end of the rod it is quickly dispersed in all directions in the form of streaming particles the attractive forces drawing it into elongated portions and the

XI *Fig 14*)

1600 A very remarkable effect is produced on these phenomena connected with positive

when charged negatively There can be no doubt that this is connected with the difference of

charged conductors and is dependent upon the mode in which these particles polarize (1503 1523)

1601 Whenever currents travel in insulating dielectrics they really effect discharge and it is important to observe though a very natural

towards it from the opposite end

160? The two currents often occur at once as when both terminations present brushes and frequently when they exhibit the glow (1531)

charged prime conductor it wi very o ten happen that two currents will form and be

and from the conductor the *principles of inductric action and charge*, which were referred to in considering the relation of a carrier ball and a conductor (1566), being here also called into play

1603 The general analogy and, I think I may say, identity of action found to exist as to insulation and conduction (1338, 1561) when bodies, the best and the *worst in the classes of* insulators or conductors, were compared, led *me to believe that the phenomena of convection* in badly conducting media were not without their parallel amongst the best conductors, such even as the metals Upon consideration, the cones produced by Davy[1] in fluid metals, as mercury and tin seemed to be cases in point, and probably also the elongation of the metallic medium through which a current of electricity was passing *described by Ampere (1113)*,[2] for it is not difficult to conceive, that the diminution of convective effect, consequent upon *the high conducting power of the metallic media* used in these experiments, might be fully compensated for by the enormous quantity of electricity passing In fact, it is impossible not to expect *some* effect whether sensible or not, of the kind in question, when such a current is passing through a fluid offering a sensible resistance to the passage of the electricity, and, thereby, giving proof of a certain degree of insulating power (1328)

1604 I endeavoured to connect the convective *currents in air, oil of turpentine, &c*, and those in metals, by intermediate cases, but *found this not easy to do On taking bodies*, for instance, which, like water, acids, solutions, *fused salts or chlorides, &c, have intermediate* conducting powers, the minute quantity of electricity which the common machine can supply (371, 861) is exhausted instantly, so that the cause of the phenomenon is kept either very low in intensity, or the instant of time during which the effect lasts is so small that one cannot hope to observe the result sought for If a voltaic battery be used, these bodies are all electrolytes, and the evolution of gas, or the production of other changes interferes and prevents observation of the effect required

1605 There are, nevertheless, some experiments which illustrate the connection Two platina wires, forming the electrodes of a powerful voltaic battery, were *placed side by side*, near each other, in distilled water hermetically *sealed up in a strong glass tube*, some minute vegetable fibres being present in the water When, from the evolution of gas and the consequent increased pressure, the bubbles formed on the electrodes were so small as to produce but feebly ascending currents, then it could be observed that the filaments present were attracted and repelled between the two wires as they would have been between two oppositely *charged surfaces in air or oil of turpentine*, moving so quickly as to displace and disturb *the bubbles and the currents which these tended* to form Now I think it cannot be doubted that under similar circumstances, and with an abundant supply of electricity, of sufficient tension also convective currents might have been formed the attractions and repulsions of the filaments were, in fact, the elements of such currents (1572), and therefore water, though *almost infinitely above air or oil of turpentine* as a conductor, is a medium in which similar currents can take place

1606 *I had an apparatus made (Pl XI, Fig 15)* in which *a* is a plate of shellac, *b* a fine platina wire passing through it, and having only the section of the wire exposed above *c* a ring of bibulous paper resting on the shellac, and *d* distilled water retained by the paper in its place, and just sufficient in quantity to cover the end of the wire *b*, another wire, *e*, touched a piece of tinfoil lying in the water, and was also connected with a discharging train, in this way it was easy, by rendering *b* either positive or negative, to send a current of electricity by its extremity into the fluid, and so *away by the wire e*.

1607 On connecting *b* with the conductor of *a powerful electrical machine not* the least disturbance of the level of the fluid over the end of the wire during the working of the machine could be observed, but at the same time there was not the smallest indication of electrical charge about the conductor of the machine, so complete was the discharge *I conclude* that the quantity of electricity passed in a *given time* had been too small, when compared with the conducting power of the fluid to produce the desired effect

1608 I then charged a large Leyden battery (291), and discharged it through the wire *b*, interposing, however, a wet thread, two feet long, to prevent a spark in the water, and to reduce what would else have been a sudden violent discharge into one of more moderate *character, enduring for a sensible length of* time (331). I now did obtain a very brief ele-

[1] *Philosophical Transactions* 1823 p 155
[2] *Bibliothèque Universelle* XXI 47

vation of the water over the end of the wire, and though a few minute bubbles of gas were at the same time formed there, so as to prevent me from asserting that the effect was unequivocally the same as that obtained by DAVY in the metals, yet, according to my best judgement, it was partly, and I believe principally, of that nature

1609 I employed a voltaic battery of 100 pair of four inch plates for experiments of a similar nature with electrolytes In these cases the shellac was cupped, and the wire b 0 2 of an inch in diameter Sometimes I used a positive amalgamated zinc wire in contact with dilute sulphuric acid, at others, a negative copper wire in a solution of sulphate of copper,

that when I made use of mercury, endeavouring to repeat DAVY's experiment, the battery of 100 pair was not sufficient to produce the elevations [1]

1610 The latter experiments (1609) may

to compare the currents at points and surfaces in such extremely different bodies as air and

action of the molecules of matter, seems to embrace the various isolated phenomena as they successively come under consideration!

1611 The connection of this convective or carrying effect, which depends upon a certain degree of insulation, with conduction i e, the occurrence of both in so many of the substances referred to, as for instance, the metals, water, air, &c, would lead to many very curious theoretical generalizations, which I must not indulge in here One point, however, I shall venture to refer to.

lead to the conclusion, that all bodies conduct, and by the same process, air as well as metals, the only difference being in the necessary degree of force or tension between the particles which must exist before the act of conduction or transfer from one particle to another can take place

1612 The question then arises, what is this limiting condition which separates, as it were, conduction and insulation from each other? Does it consist in a difference between the two contiguous particles, or the contiguous poles of these particles, in the nature and amount of

ent bodies, but always the same for the same body? Or is it true that, however small the

¶ xi *Relation of a Vacuum to Electrical Phenomena*

1613 *It would seem strange, if a theory* which refers all the phenomena of insulation and conduction, i e, all electrical phenomena, to the action of contiguous particles, were to

vacuum would be opposed to them both, and allow neither of induction or conduction across it Mr Morgan[1] has said that a vacuum does not conduct Sir H Davy concluded from his investigations, that as perfect a vacuum as could be made[2] did conduct, but does not consider the prepared spaces which he used as absolute vacua In such experiments I think I have observed the luminous discharge to be principally on the inner surface of the glass and it does not appear at all unlikely that, if the vacuum refused to conduct, still the surface of glass next it might carry on that action

1614 At one time, when I thought inductive force was exerted in right lines, I hoped to illustrate this important question by making experiments on induction with metallic mirrors (used only as conducting vessels) exposed towards a very clear sky at night time and of such concavity that nothing but the firmament could be visible from the lowest part of the concave *n* (Pl XI, *Fig 16*) Such mirrors, when electrified, as by connection with a Leyden jar, and examined by a carrier ball, readily gave electricity at the lowest part of their concavity if in a room but I was in hopes of finding that, circumstanced as before stated, they would give little or none at the same spot, if the atmosphere above really terminated in a vacuum I was disappointed in the conclusion, for I obtained as much electricity there as before, but on discovering the action of induction in curved lines (1231), found a full and satisfactory explanation of the result

1615 My theory as far as I have ventured it, does not pretend to decide upon the consequences of a vacuum It is not at present limited sufficiently, or rendered precise enough, either by experiments relating to spaces void of matter, or those of other kinds, to indicate what would happen in the vacuum case I have only as yet endeavoured to establish, what all the facts seem to prove, that when electrical phenomena, as those of induction, conduction, insulation and discharge occur, they depend on, and are produced by the action of contiguous particles of matter, the next existing particle being considered as the contiguous one and I have further assumed, that these particles are polarized, that each exhibits the two forces, or the force in two directions (1295, 1298), and that they act at a distance, only by acting on the contiguous and intermediate particles

1616 But assuming that a perfect vacuum were to intervene in the course of the lines of inductive action (1304), it does not follow from this theory, that the particles on opposite sides of such a vacuum could not act on each other Suppose it possible for a positively electrified particle to be in the centre of a vacuum an inch in diameter, nothing in my present views forbids that the particle should act at the distance of half an inch on all the particles forming the inner superficies of the bounding sphere, and with a force consistent with the well known law of the squares of the distance But suppose the sphere of an inch were full of insulating matter, the electrified particle would not then according to my notion, act directly on the distant particles but on those in immediate association with it, employing all its power in polarizing them, producing in them negative force equal in amount to its own positive force and directed towards the latter, and positive force of equal amount directed outwards and acting in the same manner upon the layer of particles next in succession So that ultimately, those particles in the surface of a sphere of half an inch radius, which were acted on directly when that sphere was a vacuum, will now be acted on indirectly as respects the central particle or source of action, i e they will be polarized in the same way, and with the same amount of force

§ 19 *Nature of the Electrical Current*

1617 The word *current* is so expressive in common language that when applied in the consideration of electrical phenomena we can hardly divest it sufficiently of its meaning or prevent our minds from being prejudiced by it (283, 511) I shall use it in its common electrical sense, namely to express generally a certain condition and relation of electrical forces supposed to be in progression

1618 A current is produced both by excitement and discharge, and whatsoever the variation of the two general causes may be, the effect remains the same Thus excitement may occur in many ways, as by friction, chemical action influence of heat, change of condition, induction, &c , and discharge has the forms of conduction, electrolyzation, disruptive discharge, and convection, yet the current connected with these actions, when it occurs, appears in all cases to be the same This constancy in the character of the current notwithstanding the particular and great variations which may be made in the mode of its occurrence is exceedingly striking and important, and its in-

[1] *Philosophical Transactions* 1785, p 272
[2] *Ibid*, 1822 p 64

vestigation and development promise to supply the most open and advantageous road to a true and intimate understanding of the nature of electrical forces

1619 As yet the phenomena of the current *have presented nothing in opposition to the* view I have taken of the nature of induction as an action of contiguous particles I have endeavoured to divest myself of prejudices and to look for contradictions, but I have not perceived any in conductive, electrolytic, convective, or disruptive discharge

1620 Looking at the current as a *cause*, it exerts very extraordinary and diverse powers, not only in its course and on the bodies in which it exists, but collaterally, as in inductive or magnetic phenomena

1621 *Electrolytic action* One of its direct actions is the exertion of pure chemical force, this being a result which has now been examined to a considerable extent The effect is found to be *constant* and *definite* for the quantity of electric force discharged (783, &c), and beyond that, the *intensity* required is in relation to the intensity of the affinity or forces to be *overcome* (904, 906 911) The current and its consequences are here proportionate, the one may be employed to represent the other, no part of the effect of either is lost or gained, so that the case is a strict one and yet it is the very case which most strikingly illustrates the doctrine that induction is an action of contiguous particles (1164, 1343)

1622 The process of electrolytic discharge

yards across a chamber, they may produce strong winds in the air, so as to move ma-

one particle of oxygen to go to another, or by which a particle of oxygen travels in the contrary direction

1623 Travelling particles of the air can effect chemical changes just as well as the contact of a fixed platina electrode, or that of a

of decomposition were rendered active by one current (469), and where charged particles of air in motion were the only electrical means of connecting these parts of the current, it seems to me that the action of the particles of the electrolyte and of the air were essentially the same A particle of air was rendered positive, it travelled in a certain determinate direction, and coming to an electrolyte, communicated its powers, an equal amount of positive force was accordingly acquired by another particle (the hydrogen), and the latter, so charged, travelled as the former did, and in the same direction, until it came to another particle, and transferred its power and motion, making that other particle active Now, though the particle of air travelled over a visible and occasionally a large space, whilst the particle of the electrolyte moved over an exceedingly small one,

it, electrified at a negative point, moves on

[1] If a metallic vessel three or four inches deep containing oil of turpentine be insulated and electri

perimenter

lation of the electric and heating forces, whether the latter is always definite in amount[1] There are many cases, even amongst bodies which conduct without change, that at present are irreconcileable with the assumption that it is,[2] but there are also many which indicate that, when proper limitations are applied, the heat produced is definite Harris has shown this for a given length of current in a metallic wire, using common electricity,[3] and De la Rive has proved the same point for voltaic electricity by his beautiful application of Breguet's thermometer[4]

1626 When the production of heat is observed in electrolytes under decomposition, the results are still more complicated But important steps have been taken in the investigation of this branch of the subject by De la Rive[5] and others, and it is more than probable that, when the right limitations are applied, constant and definite results will here also be obtained

1627 It is a most important part of the character of the current and essentially connected with its very nature, that it is always the same The two forces are everywhere in it There is never one current of force or one fluid only Any one part of the current may, as respects the presence of the two forces there, be considered as precisely the same with any other part, and the numerous experiments which imply their possible separation, as well as the theoretical expressions which, being used daily, assume it, are, I think, in contradiction with facts (511, &c) It appears to me to be as impossible to assume a current of positive or a current of negative force alone, or of the two at once with any predominance of one over the other, as it is to give an absolute charge to matter (516, 1169, 1177)

1628 The establishment of this truth, if, as I think, it be a truth, or on the other hand the disproof of it, is of the greatest consequence If, as a first principle, we can establish that the centres of the two forces, or elements of force, never can be separated to any sensible distance, or at all events not farther than the space between two contiguous particles (1615), or if we can establish the contrary conclusion, how much more clear is our view of what lies before us, and how much less embarrassed the ground over which we have to pass in attaining to it, than if we remain halting between two opinions! And if, with that feeling we rigidly test every experiment which bears upon the point, as far as our prejudices will let us (1161), instead of permitting them with a theoretical expression to pass too easily away, are we not much more likely to attain the real truth, and from that proceed with safety to what is at present unknown?

1629 I say these things, not, I hope, to advance a particular view, but to draw the strict attention of those who are able to investigate and judge of the matter, to what must be a turning point in the theory of electricity to a separation of two roads, one only of which can be right and I hope I may be allowed to go a little further into the facts which have driven me to the view I have just given

1630. When a wire in the voltaic circuit is heated, the temperature frequently rises first, or most at one end If this effect were due to any relation of positive or negative as respects the current, it would be exceedingly important I therefore examined several such cases but when, keeping the contacts of the wire and its position to neighbouring things unchanged, I altered the direction of the current, I found that the effect remained unaltered, showing that it depended, not upon the direction of the current, but on other circumstances So there is here no evidence of a difference between one part of the circuit and another

1631 The same point, i e, uniformity in every part, may be illustrated by what may be considered as the inexhaustible nature of the current when producing particular effects for these effects depend upon transfer only, and do not consume the power. Thus a current which will heat one inch of platina wire will heat a hundred inches (853, *note*) If a current be sustained in a constant state, it will decompose the fluid in one voltameter only, or in twenty others if they be placed in the circuit, in each to an amount equal to that in the single one

1632 Again, in cases of disruptive discharge, as in the spark, there is frequently a dark part (1422) which, by Professor Johnson, has been called the neutral point,[6] and this has given rise to the use of expressions implying that

[1] See De la Rive's Researches *Bib Universelle* 1829 XL, p 40

[2] Amongst others Davy *Philosophical Transactions* 1821 p 433 Pelletier's important results *Annales de Chimie* 1834 LVI p 371 and Becquerel's non heating current *Bib Universelle* 1835 LX, 218

[3] *Philosophical Transactions* 1824 pp. 225 228

[4] *Annales de Chimie* 1836 LXII 177

[5] *Bib Universelle*, 1829 XL, 49 and Ritchie *Phil Trans* 1832, p. 296.

[6] *Silliman's Journal*, 1834 XXV, p 57

there are two electricities existing separately,

such a case, one part of a current would consist of positive electricity only, and that moving in one direction, another part would consist of negative electricity only, and that moving in the other direction and a third part

to me to be natural In a current, whatever form the discharge may take, or whatever part

manner, one being charged with five, ten, or twenty times as much of both positive and negative electricity in equal quantities as another At present, however, there is no known fact indicating such states

1633 Even in cases of convection or carrying discharge, the statement that the current is everywhere the same must in effect be true (1627), for how, otherwise, could the results formerly described occur? When currents of air constituted the mode of discharge between

the occurrence of a spark, or the passage of convective currents either one way or the other (depending on the electrified state of the particles), the result was the same, being in all cases dependent upon the perfect current

[1] Thomson on *Heat and Electricity* p 471

1634 Hence, the section of a current compared with other sect

are produced are equivalent to each other, and experimentally convertible at pleasure It is in sections therefore, we must look for identity of electrical force, even to the sections of sparks and carrying actions, as well as those of wires and electrolytes

1635 In illustration of the utility and importance of establishing that which may be the true principle I will refer to a few cases The

and the later singular phenomena of poles and flames described by Erman and others[3] partake of the same inconsistency of character If a unipolar body could exist, i e, one that could conduct the one electricity and not the other, what very new characters we should have a

[3] Erman *Annales de Chimie* 1824 XXV, 278 Becquerel *Ibid* XXXVI p 329

[4] Becquerel *Annales de Chimie* 1831 XLVI p 283

[5] Andrews *Philosophical Magazine* 1836 IX 182

[6] Schweigger's *Jahrbuch der Chimie* &c 1830

1636 I conclude, *therefore that the facts* upon which the doctrine of unipolarity was founded are not adverse to that unity and indivisibility *of character* which I have *stated* the current to possess, any more than the phenomena of the pile itself (which might well bear comparison with those *of unipolar bodies*), are opposed to it Probably the effects which have been called effects of unipolarity, and the peculiar differences of the positive and negative surface when discharging into air, gases or other dielectrics (1480, 1525) which have been already referred to, may have considerable relation to each other [1]

1637 M de la Rive has *recently* described a peculiar and remarkable effect of heat on a current when passing between electrodes and a fluid [2] It is, that if platina electrodes dip into acidulated water, no change is produced in the passing current by making the positive electrode hotter or colder whereas making the negative electrode hotter increased the deflexion of a galvanometer affected by the current from 12° to 30° and even 45°, whilst making it colder diminished the current in the same high proportions

1638 That one electrode should have this striking relation to heat whilst the other *remained absolutely without*, seem *to me as* incompatible with what I conceived to be the character of a current as unipolarity (1627, 1635), and it was *therefore with some anxiety* that I repeated the experiment The electrodes which I used were platina the electrolyte, water containing about one sixth of sulphuric acid by weight the voltaic battery consisted of two pairs of amalgamated zinc and platina plates in dilute sulphuric acid, and the galvanometer in the circuit was one with two needles, and gave when the *arrangement* was *complete* a deflexion of 10° or 12°

1639 Under these circumstances heating *either electrode increased the current* heating both produced still more effect When both were heated if either were cooled, the effect on the *current* fell *in proportion* The *proportion* of effect due to heating this or that electrode varied but on the whole heating the negative *seemed* to favour the passage of the current somewhat more than heating the positive. Whether the application of *heat* were by a flame applied underneath, or one directed by a blow pipe *from above* or by a hot iron or coal, the effect was the same

1640 Having thus removed the difficulty *out of the way of my views regarding a current*, I did not pursue this curious experiment further It is probable that the difference between *my results and those of* M de la Rive may depend upon the relative values of the currents used, for I employed only a weak one *resulting from two pairs of* plates two *inches* long and half an inch wide, whilst M de la Rive used four pairs of plates of sixteen square inches *in surface*

1641 Electric discharges in the atmosphere in the form of balls of fire have occasionally been described Such phenomena appear to me to be incompatible with all that we know *of* electricity and its modes of discharge *As time* is an element in the effect (1418 1436) it is possible *perhaps that* an electric discharge *might* really pass as a ball from place to place but as everything shows that its velocity must be almost *infinite* and the time of *its* duration exceedingly small it is impossible that the eye should perceive it as anything else than a line *of light* *That phenomena of balls of fire may* appear in the atmosphere I do not mean to deny but that they have anything to do with *the discharge of ordinary electricity*, or are at all related to lightning or atmospheric electricity, is much more than doubtful

1642 All these considerations, and many others help to confirm the conclusion drawn over and over again, that the current is an indivisible thing an axis of power, in every part of which both *electric forces* are *present* in equal amount[3] (517, 1627) With conduction and electrolyzation, and even discharge by spark, *such a view will harmonize* without hurting any of our preconceived notions but as relates to convection a *more startling result* appears, *which must therefore* be considered

1643 If two balls A and B be electrified in opposite states and held within each *other's* influence, the moment they move towards each other, a current, or those effects which are understood by the word current, will be *produced* Whether A move towards B, or B move in the opposite direction towards A, a current and in *both cases having the same direction* will re-

[1] See also Hare in *Silliman's Journal* 1833 XXIV 246.

[2] *Bibliothèque Universelle* 1837 VII 388.

[3] I am glad to refer here to the results obtained by Mr Christie with magneto-electricity *Philosophical Transactions* 1833 p 113 note As regards the current in a wire they confirm everything that I am contending for

sult If A and B move from each other, then a *current* in the opposite direction, or equivalent effects, will be produced

1644 Or, as charge exists only by induction (1178 1299), and a body when electrified is necessarily in relation to other bodies in the opposite state, so if a ball be electrified positively in the middle of a room and be then moved in any direction effects will be produced, as if a *current* in the same direction (to

formed, will be produced

1645 I am saying of a single particle or of two what I have before said in effect, of many (1633) If the former account of currents be true then that just stated must be a necessary

the intermediate particles (1165 1295) these becoming polarized exactly as the particles of a solid electrolyte do when interposed between the two electrodes Hence the conclusion regarding the unity and identity of the current in the case of convection, jointly with the former cases, is not so strange as it might at first appear

1646 There is a very remarkable phenomenon or effect of the electrolytic discharge first pointed out I believe, by Mr Porrett of the accumulation of fluid under decomposing action in the current on one side of an interposed diaphragm[1] It is a mechanical result and as the liquid passes from the positive towards the negative electrode in all the known cases it seems to establish a relation to the polar condition of the dielectric in which the current

the electric current

1647 Becquerel, in his *Traité de l Electricité*, has brought together the considerations which arise for and against the opinion that the effect generally is an electric effect[4] Though I have no decisive fact to quote at present, I cannot refrain from venturing an opinion that the effect is analogous both to combination

electric discharge is jointly effected and further, that the peculiar relation of positive and

very valuable experiment has been made by M Becquerel with particles of clay,[5] which will probably bear importantly on this point

1648 *As long as* the terms *current* and *electro-dynamic* are used to express those rela

fluid or fluids be adopted

1649 Hence has arisen the desire of esti

tricity in the early trials being supposed to *travel from end to end of the arrangement* but in the later investigations a distinction occasionally appearing to be made between the transmission of the effect and of the supposed fluid by the motion of whose particles that effect is produced

ation and as the amount of power is definite, we have in this way a means of localizing as it were the force, identifying it by the particle

[1] *Annals of Philosophy* 1816 VIII p 75
[2] *Annales de Chimie* 1835, XXVIII p 190
[3] *Annales de Chimie* 1832 XLIX p 423

[4] Vol IV p 19 197
[5] *Traité de l Electricité* I p 285
[6] *Philosophical Transactions* 1748
[7] *Ib.*

voltaic battery. Each particle of hydrogen as it moves one way, or of oxygen as it moves in the other direction, will transfer a certain amount of electrical force associated with it in the form of chemical affinity (822, 852, 918) onwards *through a distance, which is equal to that through* which the particle itself has moved This transfer will be accompanied by a corresponding movement in the electrical forces throughout every part of the circuit formed (1627, 1634), and its effects may be estimated, as, for instance, by the heating of a wire (853) at any particular section of the current however distant If the water be a cube of an inch in the side, the electrodes touching, each by a surface of one square inch, and being an inch apart, *then, by the time that a tenth of it*, or 25 25 grains, is decomposed, the particles of oxygen and hydrogen throughout the mass may be considered as having moved relatively to each other in opposite directions, to the amount of the tenth of an inch i e, that two particles at first in combination will after the motion be the tenth of an inch apart Other motions which occur in the fluid will not at all interfere with this result, for they have no power of accelerating or retarding the electric discharge, and possess *in fact no relation to it*

1652 The quantity of electricity in 25.25 grains of water is, according to an estimate of the force which I formerly made (861), equal to above 24 millions of charges of a large Leyden battery or it would have kept any length of a platina wire $\frac{1}{104}$ of an inch in diameter red hot for an hour and a half (853) This result, though given only as an approximation, I have seen no *reason as yet to alter*, and *it is* confirmed generally by the experiments and results of M Pouillet [1] According to Mr Wheatstone's experiments, the influence or effects of the current would appear at a distance of 576, 000 miles in a second [2] We have, therefore, in this view of the matter, on the one hand, an enormous quantity of power equal to a most destructive thunder-storm appearing instantly at the distance of *576,000 miles from* its source, and on the other, a quiet effect, in producing which the power *had taken* an hour and a half to travel through the tenth of an inch yet these are the equivalents to each other, being effects observed at the sections of one and the same current (1634)

1653 It is time that I should call attention to the lateral or transverse forces of the *current* The great things which have been achieved by Oersted, Arago, Ampère Davy, De la Rive, and others, and the high degree of simplification which has been introduced into their arrangement by the theory of Ampère, have not *only done their full service in advancing most* rapidly this branch of knowledge, but have secured to it such attention that *there is no necessity* for urging on its pursuit I refer of course to magnetic action and its relations, but though this is the only recognised lateral action of the current, there is great reason for believing that others exist and would by their discovery reward a close search for them (951)

1654 The magnetic or transverse action of the current seems to be in a most extraordinary *degree independent of those variations or* modes of action which it presents directly in its course, *it consequently is of the more* value to us, as it gives us a higher relation of the power than any that might have varied with each mode of discharge This discharge, whether it be by conduction through a wire with infinite velocity (1652), or by electrolyzation with its corresponding and exceeding slow motion (1651), or by spark, and probably even by convection, produces a transverse magnetic action *always the same in kind and direction*.

1655 It has been shown by several experimenters that whilst the discharge is of the *same kind* the amount of lateral or magnetic force is very constant (216, 366, 367, 368, 376) But when we wish to compare discharge of different kinds, for the important purpose of ascertaining whether the same amount of current will in its *different forms* produce the same amount of transverse action, we *find the* data very imperfect Davy noticed that when the *electric current* was passing through an aqueous solution it affected a magnetic needle,[3] and Dr Ritchie says, that the current in the electrolyte is as magnetic as that in a metallic wire,[4] and has caused water to revolve round a magnet as a wire carrying the current would revolve

1656 Disruptive discharge produces its magnetic effects a strong spark, passed transversely *to a steel needle*, will magnetise it as well as if the electricity of the spark were conducted by a metallic wire occupying the line of discharge and Sir H Davy has shown that the discharge of a voltaic battery *in vacuo* is affected and has motion given to it by approximated magnets.[5]

[1] Becquerel *Traité de l'Electricité*, V, p 278.
[2] *Philosophical Transactions* 1834 p. 589
[3] *Philosophical Transactions* 1821, p. 425.
[4] *Ibid*, 1832 p 294.
[5] *Ibid*., p 427

1657 Thus the three very different modes of [illegible]

charge will [illegible]

[illegible]

1658 Having arrived at this point in the consideration of the current and in the endeavour to apply its phenomena as tests of the truth or fallacy of the theory of induction which I have ventured to set forth, I am now very m[illegible]

[illegible]

asso[illegible]

[illegible]

their correspondent transverse condition or effect (951)

1659 According to the beautiful theory of Ampère the [illegible]

[illegible]

of static electricity be represented by that lateral te[illegible]

[illegible]

force will weaken and fade away and, as their lateral [illegible]

[illegible]

may not the passage of static electricity into current electricity, and that of the lateral tension of the lines of inductive force into the lateral attraction of lines of similar discharge, have the same relation and dependences, and run parallel to each other?

1660 The phenomena of induction amongst currents which I had the good fortune to discover some years ago (6, &c , 1048) may per-

[1] Refer for further investigations to 1709—1736. —*Dec* 1838.

chance here form a connecting link in the series of effects [illegible]

[illegible]

the contrary, when the original current is stopped [illegible]

[illegible]

1661 Now though we perceive the effects only in that portion of matter which being in [illegible]

[illegible]

has been shown to be one not of opposition in kind, but only of degree (1334, 1603) and, therefore [illegible]

[illegible]

1662 It is the feeling of the necessity of some lateral connection between the lines of [illegible]

[illegible]

on the introduction of insulating dielectrics having different inductive capacities (1270, 1277) between magnetic poles and wires carrying currents so as to pass across the lines of magnetic force I have employed such bodies both at rest and in motion without as yet, being able to detect any influence produced by them but I do by no means consider the experiments as sufficiently delicate and intend very shortly, to render them more decisive[1]

1663 I think the hypothetical question may at present be put thus can such considerations as those already generally expressed (1658) account for the transverse effects of electrical currents? are two such currents in relation to each other merely by the inductive condition of the particles of matter between them or are they in relation by some higher quality and condition (1654) which acting at a distance and not by the intermediate particles has like the force of gravity no relation to them?

1664 If the latter be the case, then when electricity is acting upon and in matter, its direct and its transverse action are essen-

[1] See onwards 1711—1726.—*Dec* 1838.

tially different in their nature, for the former, if I am correct will depend upon the contiguous particles and the latter will not As I have said before this may be so and I incline to that view at present but I am desirous of suggesting considerations why it may not that the question may be thoroughly sifted

1665 The transverse power has a character of polarity impressed upon it In the simplest forms it appears as attraction or repulsion, according as the currents are in the same or different directions in the current and the magnet it takes up the condition of tangential forces and in magnets and their particles produces poles Since the experiments have been made which have persuaded me that the polar forces of electricity, as in induction and electrolytic action (1298 1343), show effects at a distance only by means of the polarized contiguous and intervening particles I have been led to expect that *all polar forces* act in the same general manner, and the other kinds of phenomena *which one can bring to bear upon the subject* seem fitted to strengthen that expectation Thus in crystallizations the effect is transmitted from particle to particle and in this manner in acetic acid or freezing water a crystal a *few inches or even a couple of feet in length* will form in less than a second but progressively and by a transmission of power from particle to particle And, as far as I remember no case of polar action, or partaking of polar action except the one under discussion can be found which does not act by contiguous particles.[1] It is apparently of the nature of polar forces that such should be the case for the one force either finds or develops the contrary force near to it and has, therefore, no occasion to seek for it at a distance

1666 *But leaving these hypothetical notions* respecting the nature of the lateral action out of sight, and returning to the direct effects I think that the phenomena examined and reasoning employed in this and the two preceding papers tend to confirm the view first taken (1164) namely that ordinary inductive action and the effects dependent upon it are due to an action of the contiguous particles of the dielectric interposed between the charged surfaces or parts which constitute, as it were, the terminations of the effect The great point of distinction and power (if it have any) in the theory is *the making the dielectric of essential and specific importance* instead of leaving it as it were a mere accidental circumstance or the simple representative of space, having no more influence over the phenomena than the space occupied by it *I have still certain other results* and views respecting the nature of the electrical forces and excitation, which are connected with the present theory, and unless upon further consideration they sink in my estimation *I shall very shortly put them into form* as another series of these electrical researches

Royal Institution February 14 1838

[1] I mean by contiguous particles those which are next to each other not that there is *no space* between them See (1616)

FOURTEENTH SERIES

§ 20 *Nature of the Electric Force or Forces* § 21 *Relation of the Electric and Magnetic Forces* § 22 *Note on Electrical Excitation*

RECEIVED JUNE 21, 1838, READ JUNE 21, 1838

§ 20 *Nature of the Electric Force or Forces*

1667 THE theory of induction set forth and illustrated in the three preceding series of experimental researches does *not assume anything* new as to the nature of the electric force or forces, but only as to their distribution The effects may depend upon the association of one electric fluid with the particles of matter, as in the theory of Franklin, Epinus Cavendish, and Mossotti or they may depend upon the association of two electric fluids as in the theory of Dufay and Poisson, or they may not depend upon anything which can properly be called the electric fluid but on vibrations or *other affections* of the matter in which they appear The theory is unaffected by such differences in the mode of *viewing the nature of* the forces and though it professes to perform the important office of stating *how* the powers are arranged (at least in inductive phenomena) it does not as far as I can yet perceive supply a single experiment which can be considered as

a distinguishing test of the truth of any one of these various views

1668 But, to ascertain how the forces are arranged, to trace them in their various relations to the particles of matter, to determine their general laws, and also the specific differences which occur under these laws, is as important as, if not more so than to know whether the forces reside in a fluid or not, and with the hope of assisting in this research, I shall offer some further developments, theoretical and experimental, of the conditions under which I suppose the particles of matter are placed when exhibiting inductive phenomena

1669 The theory assumes that all the *particles*, whether of insulating or conducting matter, are as wholes conductors

1670 That not being polar in their normal state, they can become so by the influence of neighbouring charged particles, the polar state being developed at the instant, exactly as in an insulated conducting *mass* consisting of many particles

1671 That the particles when polarized are in a forced state, and tend to return to their normal or natural condition

1672 T[illegible]

[illegible] municate or transfer their polar forces one to another *more* or *less* readily

1674 That those doing so less readily require the polar forces to be raised to a higher degree before this transference or communication takes place

1675 That the *ready* communication of forces between contiguous particles constitutes *conduction* and the *difficult* communication *insulation*, conductors and insulators being bodies whose [illegible]

property

1676 That ordinary induction is the effect resulting from the action of matter charged with excited or free electricity upon insulating matter, tending to produce in it an equal amount of the contrary state

1677 That it can do this only by polarizing the particles contiguous to it, which perform the same office to the next, and these again to those beyond, and that thus the action is propagated from the excited body to the next conducting mass, and there renders the contrary force evident in consequence of the effect of communication which supervenes in the conducting mass upon the polarization of the particles of that body (1675)

1678 That therefore induction can only take place through or across insulators that induction is insulation, it being the necessary consequence of the state of the particles and the mode in which the influence of electrical forces is transferred or transmitted through or across such insulating media

1679 The particles of an insulating dielectric whilst under induction may be compared to a series of small magnetic needles, or more correctly still to a series of small insulated conductors If the space round a charged globe were filled with a mixture of an insulating dielectric, as oil of turpentine or air, and small globular conductors, as shot, the latter being at a little distance from each other so as to be insulated, then these would in their condition and action exactly resemble what I consider to be the condition and action of the particles of the insulating dielectric itself (1337) If the globe were charged, these little conductors would all be polar if the globe were discharged, they would all return to their normal state to [illegible]

[1] See note to 1164 —*Dec* 1838

and leave those *near* it, namely the particles of the dielectric, unaffected and everything in the form of fact and experiment with conducting masses or particles of a sensible size contradicts such a supposition

1681 A striking character of the electric power is that it is limited and exclusive and that the two forces being always present are exactly equal in amount The forces are related in one of two ways either as in the natural normal condition of an uncharged insulated conductor, or as in the charged state, the latter being a case of induction

1682 Cases of induction are easily arranged so that the two forces being limited in their direction shall present no phenomena or indications external to the apparatus employed Thus, *if a Leyden jar, having its external coating a* little higher than the internal, be charged and then its charging ball and rod removed, such jar will present no electrical appearances so long as its outside is uninsulated The two forces which may be said to be in the coatings, or in the particles of the dielectric contiguous to them, are entirely engaged to each other by induction through the glass, and a carrier ball (1181) applied either to the inside or outside of the jar will show no signs of electricity But *if the jar be insulated and the charging ball and* rod, in an uncharged state and suspended by an insulating thread of white silk, be restored to their place, then the part projecting above the jar will give electrical indications and charge the carrier, and at the same time the *outside* coating of the jar will be found in the opposite state and inductric towards external surrounding objects

1683 These are simple consequences of the theory Whilst the charge of the inner coating *could induce only through the glass towards* the outer coating, and the latter contained no more of the contrary force than was equivalent to it, no induction external to the jar could be perceived, but when the inner coating was extended by the rod and ball so that it could induce through the air towards external objects, then the tension of the polarized glass molecules would, by their tendency to return to the normal state, fall a little, and a portion of the charge passing to the surface of this new part *of the inner conductor, would produce inductive* action through the air towards distant objects, whilst at the same time a part of the force in the outer coating previously directed inwards would now be at liberty, and indeed be constrained to induct outwards through the air, producing in that outer coating what is sometimes called, though I think very improperly, free charge If a small Leyden jar be converted into that form of apparatus usually known by the name of the electric well, it will illustrate this action very completely.

1684 The terms *free charge* and *dissimulated electricity* convey therefore erroneous notions if they are meant to imply any difference as to the mode or kind of action The charge upon an insulated conductor in the middle of a room is in the same relation to the walls of that room as the charge upon the inner coating of a Leyden jar is to the outer coating of the same jar The one is not more *free* or more *dissimulated* than the other, and when sometimes we make electricity appear where it was not evident before, *as upon the outside of a charged jar*, when, after insulating it, we touch the inner coating it is only because we divert more or less of the inductive force from one direction into another, for not the slightest change is in such circumstances impressed upon the character or action of the force

1685 Having given this general theoretical view, I will now notice particular points relating to the nature of the assumed electric polarity of the insulating dielectric particles

1686 The polar state may be considered in common induction as a forced state, the particles tending to return to their normal condition It may probably be raised to a very high degree by approximation of the inductric and inducteous bodies or by other circumstances, and the phenomena of electrolyzation (861, 1652, 1706) seem to imply that the quantity of power which can thus be accumulated on a single particle is enormous Hereafter we may be *able to compare corpuscular forces as those of* gravity cohesion, electricity, and chemical affinity, and in some way or other from their effects deduce their relative equivalents, at present we are not able to do so, but *there seems no* reason to doubt that their electrical, which are at the same time their chemical forces (891, 918), will be by far the most energetic

1687 I do not consider the powers when developed by the polarization as limited to two distinct points or spots on the surface of each particle to be considered as the poles of an axis, but as resident on large portions of that surface as they are upon the surface of a conductor of sensible size when it is thrown into a polar state *But it is very probable, notwithstanding* that the particles of different bodies may pre-

sent specific differences in this respect, the

such differences as these that we may attribute the specific actions of the different dielectrics in relation to discharge (1394, 1508) Thus with respect to oxygen and nitrogen singular contrasts were presented when spark and brush discharge were made to take place in these gases, as may be seen by reference to the table

come polarized in all directions, for a mass when experimented upon so as to ascertain its inductive capacity in three or more directions (1690), gives no indication of a difference Now as the particles are fixed in the mass, and as the direction of the induction through them must change with its change relative to the *mass the constant effect indicates that they* can be polarized electrically in any direction This accords with the view already taken of each particle as a whole being a conductor (1669) and as an experimental fact, helps to confirm that view

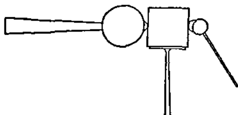
may not tend to polarize to a greater degree or with more facility, in one direction than another or that different kinds may not have specific differences in this respect as they have differences of conducting and other powers (1296 1326, 1395) I sought with great anxiety

they were developed experimented very carefully with them *I was the more strongly stim*

My experiments have not established any connexion of the kind sought for But as I think it of equal importance to shew either that there is or is not such a relation, I shall briefly describe the results

1690 The form of experiment was as follows A brass ball 0 73 of an inch in diameter, fixed at the end of a horizontal brass rod, and that at the end of a brass cylinder, was by means of

ducteous ball was the carrier of the torsion electrometer (*1229, 1314*), and the dielectric between them was a cube cut from a crystal so that two of its faces should be perpendicular to the optical axis whilst the other four were parallel to it A small projecting piece of shellac was fixed on the inductric ball at that part opposite to the attachment of the brass rod for the purpose of preventing actual contact between the ball and the crystal cube A coat of shellac was also attached to that side of the carrier ball which was to be towards the cube, *being also that side which was farthest from*



the repelled ball in the electrometer when placed in its position in that instrument The cube was covered with a thin coat of shellac dis-

ductric ball

1691 *Thus it was easy to bring the* inducteous ball always to the same distance from the

a second observation Or it was easy by revolving the stand which supported the cube to bring four of its faces in succession towards the inductric ball, and so observe the force when the lines of inductive action (1304) coincided with, or were transverse to, the direction of the optical axis of the crystal Generally from twenty to twenty-eight observations were made in succession upon the four vertical faces of a cube, and then an average expression of the inductive force was obtained, and compared with similar averges obtained at other times, every precaution being taken to secure accurate results

1692 The first cube used was of *rock crystal* it was 0 7 of an inch in the side It presented a remarkable and constant difference, the average of not less than 197 observations, giving 100 for the specific inductive capacity in the direction coinciding with the optical axis of the cube, whilst 93 59 and 93 31 were the expressions for the two transverse directions

1693 But with a second cube of rock crystal corresponding results were not obtained It was 0 77 of an inch in the side The average of many experiments gave 100 for the specific inductive capacity coinciding with the direction of the optical axis, and 98 6 and 99 92 for the two other directions

1694 Lord Ashley, whom I have found ever ready to advance the cause of science, obtained for me the loan of three globes of rock crystal belonging to Her Grace the Duchess of Sutherland for the purposes of this investigation Two had such fissures as to render them unfit for the experiments (1193, 1698) The third which was very superior, gave me no indications of any difference in the inductive force for different directions

1695 I then used cubes of Iceland spar One 0.5 of an inch in diameter gave 100 for the axial direction, and 98 66 and 95 74 for the two cross directions The other, 0 8 of an inch in the side, gave 100 for the axial direction, whilst 101 73 and 101 86 were the numbers for the cross direction

1696 Besides these differences there were others, which I do not think it needful to state, since the main point is not confirmed For though the experiments with the first cube raised great expectation, they have not been generalized by those which followed I have no doubt of the results as to that cube, but they cannot as yet be referred to crystallization There are in the cube some faintly coloured layers parallel to the optical axis, and the matter which colours them may have an influence, but then the layers are also nearly parallel to a cross direction, and if at all influential should shew some effect in that direction also, which they did not

1697 In some of the experiments one half or one part of a cube showed a superiority to another part, and this I could not trace to any charge the different parts had received It was found that the varnishing of the cubes prevented any communication of charge to them, except (in a few experiments) a small degree of the negative state, or that which was contrary to the state of the inductric ball (1564, 1566)

1698 I think it right to say that, as far as I could perceive, the insulating character of the cubes used was perfect, or at least so nearly perfect, as to bear a comparison with shellac, glass &c (1255) As to the cause of the differences, other than regular crystalline structure, there may be several Thus minute fissures in the crystal insensible to the eye may be so disposed as to produce a sensible electrical difference (1193) Or the crystallization may be irregular or the substance may not be quite pure, and if we consider how minute a quantity of matter will alter greatly the conducting power of water, it will seem not unlikely that a little extraneous matter diffused through the whole or part of a cube, may produce effects sufficient to account for all the irregularities of action that have been observed

1699 An important inquiry regarding the electrical polarity of the particles of an insulating dielectric, is, whether it be the molecules of the particular substance acted on, or the component or ultimate particles, which thus act the part of insulated conducting polarizing portions (1669)

1700 The conclusion I have arrived at is that it is the molecules of the substance which polarize as wholes (1347), and that however complicated the composition of a body may be, all those particles or atoms which are held together by chemical affinity to form one molecule of the resulting body act as one conducting mass or particle when inductive phenomena and polarization are produced in the substance of which it is a part

1701 This conclusion is founded on several considerations Thus if we observe the insulating and conducting power of elements when they are used as dielectrics, we find some as sulphur, phosphorus, chlorine iodine &c, whose particles insulate, and therefore polarize in a

high degree whereas others as the metals give scarcely any indication of possessing a sensible proportion of this power (1328) their particles freely conducting one to another Yet when these enter into combination they form substances having no direct relation apparently in this respect to the r elements for water sulphuric ac d and such compounds formed of insulating elements conduct by comparison freely whilst oxide of lead flint glass borate of lead and other metallic compounds con taining very high proportions of conducting matter insulate excellently well Taking oxide of lead therefore as the illustration I conceive that it is not the particles of oxygen and lead which polarize separately under the act of in duction but the molecules of oxide of lead which exhibit this effect all the elements of one

1702 In bodies which are electrolytes we have still further reason for believing in such a state of things Thus when water chloride of tin iodide of lead &c in the solid state are between the electrodes of the voltaic battery the r particles polarize as those of any other insulating dielectric do (1164) but when the liquid state is conferred on these substances the polarized particles divide the two halves each in a h ghly charged state travelling on wards until they meet other part cles in an opposite and equally charged state with which they combine to the neutralization of their chemical i e their electrical forces and the reproduction of compound particles which can again polarize as wholes and again divide to repeat the same series of actions (1347)

and the bearing of such an opinion on the gen eral effects of induction whether ordinary or electrolytic will be my excuse I trust for a

chemical i e the electrical forces of their elements [918]) rather divide than discharge to each other without division (1348) for if their divis on i e their decomposit on and recombi nation be prevented by giving them the solid state then they will insulate electricity perhaps a hundred fold more intense than that necessary for heir electrolyzation (419 &c) Hence the tension necessary for direct conduction in such bodies appears to be much higher than that for decomposition (419 1164 1344)

is common to all insulating matter when under induction though attended by such peculiar electro-chemical results in the case of electrolytes Thus it may be expected that the first effect of induction is so to polarize and arrange the particles of water that the positive or hy

oxygen and hydrogen of a particle of water have

tained

1706 When decomposition happens in a fluid

for that plane is summed up on one or

particles, which decomposing, travelling and recombining, restore the balance of ... much as in the case ...

... less favour- ... than others, so there must be some which are most favourably disposed, and these, by giving way first, will for the time lower the tension and produce discharge

1707 In former investigations of the action of electricity (821, &c) it was shown, from many satisfactory cases, that the quantity of electric power transferred onwards was in proportion to and was definite for a given quantity of matter moving as anion or cathion onwards in the electrolytic line of action, and there was strong reason to believe that each of the particles of matter then dealt with, had associated with it a definite amount of electrical force, constituting its force of chemical affinity, the chemical equivalents and the electro-chemical equivalents being the same (836) It was also found with few, and I may now perhaps say with no exceptions (1341), that only those com- pounds containing elements ... tions ... ena ... , and other ... more than one proportion of the electro-negative element refusing to decompose under the influence of the electric current

1708 Probable reasons for these conditions and limitations arise out of the molecular theory of induction Thus when a liquid dielectric, as chloride of tin, consists of molecules, each composed of a single particle of each of the elements, then as these can convey equivalent opposite forces by their separation in opposite directions, both decomposition and transfer can result But when the molecules, as in the bichloride of tin, consist of one particle or atom of one element, and two of the ... simplic... posed ... And, ... the m... as w... , the posit... ... might accumulate on the one particle of tin whilst the negative polar force accumulated on the two particles of chlorine associated with it ... ... compounds con- ... of single proportions, yet this is not altogether so evident or probable For when a particle of tin combines with two of *chlorine* it is difficult to conceive that there should not be some relation of the three in the resulting molecule analogous to fixed position, the one particle of metal being perhaps symmetrically placed in relation to the two of chlorine and, it is not difficult to conceive of such *particles that they* could not assume that position dependent both on their polarity and the *relation* of their elements, which appears to be the first step in the *process of electrolyzation (1345, 1705)*

§ 21 *Relation of the Electric and Magnetic Forces*

1709 I have *already ventured a few* speculations respecting the probable relation of magnetism, as the transverse *force* of the current, to the divergent or transverse force of the lines of inductive action belonging to static electricity (1658, &c)

1710 In the further consideration of this subject it appeared to me to be of the utmost importance to ascertain, if possible, whether this lateral action which we call magnetism, or sometimes the induction of electrical currents (26, 1048, &c), is extended to a distance *by the action of the intermediate particles* in analogy with the induction of static electricity, or the various effects, such as conduction, discharge, &c , which are dependent on that induction, or, whether its influence at a distance is altogether independent of such intermediate particles (1662)

1711 I arranged two magneto-electric helices with iron cores end to end, but with an interval of an inch and three-quarters between them, in which interval was placed the end or pole of a bar magnet It is evident, that on moving the magnetic pole from one core towards the other, a current would tend to form in both helices *in* the one because of the lowering, and in the other because of the strengthening *of the magnetism* induced in the respective soft iron cores The helices were connected together, *and also* with a galvanometer so that these two currents should coincide in direction *and tend to* their joint force ... strumen... fective a... pole abo... or three ... quired fo... needle, w... bration in ... consequen...

of the magnet and cores, plates of substances were interposed Thus calling the two cores A and B, a plate of shellac was introduced between the magnetic pole and A for the time occupied by the needle in swinging one way, then it was withdrawn for the time occupied in the return swing introduced again for another equal portion of time, withdrawn for another portion and so on eight or nine times, but not the least effect was observed on the needle In other cases the plate was alternated i e, it was introduced between the magnet and A for one period of time, withdrawn and introduced between the magnet and B for the second period, withdrawn and restored to its first place for the third period, and so on, but with no effect on the needle

1713 In these experiments *shellac* in plates 0 9 of an inch in thickness, *sulphur* in a plate 0 9 of an inch in thickness and *copper* in a plate 0 7 of an inch in thickness were used without any effect And I conclude that bodies contrasted by the extremes of conducting and insulating power, and opposed to each other as

upon the galvanometer was produced

1716 A plate of shellac 0 6 of an inch in

direction of the rotation being also changed in different experiments, but not the least effect was produced

1718 I now removed the helices with their soft iron cores, and replaced them by two *flat* *helices* wound upon cardboard, each contain-

bration of the galvanometer needle

1719 The introduction of plates of shellac, sulphur, or copper into the intervals between the magnet and these helices (1713) produced not the least effect whether the former were quiescent or in rapid revolution (1715) So here no evidence of the influence of the intermediate particles could be obtained (1710)

ic current could be sent through it at pleasure The former galvanometer was removed, and one with a double coil employed, one of the lateral helices being connected with one coil, and the other helix with the other coil, in such manner that when a voltaic current was sent

needle remained stationary notwithstanding their frequent production in the instrument I will call the middle coil C, and the external coils A and B

been there (65)

1722 Then for the copper plate was substituted one of sulphur 0 9 of an inch thick, still the results were exactly the same, i e, there was no action at the galvanometer

1723 Thus it appears that when a voltaic current in one wire is exerting its inductive action to produce a contrary or a similar current in a neighbouring wire, according as the primary current is commencing or ceasing, it makes not the least difference whether the intervening space is occupied by such insulating bodies as air, sulphur and shellac, or such [illegible] as conn[illegible]

[illegible] obtained wit[illegible] when resident in a magnet thus A single flat helix (1718) was connected with a galvanometer, and a magnetic pole placed near to it then by moving the magnet to and from the helix, or the helix to and from the magnet, currents were produced indicated by the galvanometer

1725 The thick copper plate (1721) was afterwards interposed between the magnetic pole and the helix, nevertheless on moving these to and fro, effects exactly the same in direction and amount, were obtained as if the copper had not been there So also on introducing a plate of sulphur into the interval not the least influence on the currents produced by motion of the magnet or coils could be obtained

1726 These results with many others which I have not thought it needful to describe, would lead to the conclusion that (judging by the *amount* of effect produced at a distance by forces transverse to the electric current, i e, magnetic forces), the intervening matter, and therefore the intervening particles, have nothing to do with the phenomena or in other words, that though the inductive force of static electricity is transmitted to a distance by the action of the intermediate particles (1164, 1666), the transverse inductive force of currents, which can also act at a distance, is not transmitted by the intermediate particles in a similar way

1727 It is however very evident that such a conclusion cannot be considered as proved Thus when the metal copper is between the *pole and the helix (1715, 1719, 1725) or between* the two helices (1721) we know that its particles are affected, and can by proper arrangements make their peculiar state for the time very evident by the production of either electrical or magnetical effects It seems impossible to consider this effect on the particles of the intervening matter as independent of that produced by the inductric coil or magnet C, on the inducteous coil or core A (1715, 1721), for since the inducteous body is equally affected by the inductric body whether these intervening and affected particles of copper are present or not (1723, 1725), such a supposition would imply that the particles so affected had no reaction back on the original inductric forces The more reasonable conclusion, as it appears to me, is, to consider these affected particles as efficient in continuing the action onwards from the inductric to the inducteous body, and by this very communication producing the effect of *no loss* of induced power at the latter

1728 But then it may be asked what is the relation of the particles of insulating bodies, such as air, sulphur, or lac, when *they* intervene in the line of magnetic action? The answer to this is at present merely conjectural I have long thought there must be a particular condition of such bodies corresponding to the state which causes currents in metals and other conductors (26 53, 191, 201, 213), and considering that the bodies are insulators one would expect that state to be one of tension I have by rotating non conducting bodies near magnetic poles and poles near them, and also by causing powerful electric currents to be suddenly formed and to cease around and about insulators in various directions, endeavoured to make some such state sensible, but have not succeeded Nevertheless, as any such state must be of exceedingly low intensity, because of the feeble intensity of the currents which are used to induce it, it may well be that the state may exist, and may be discoverable by some more experimentalist, though I have not been able to make it sensible

1729 It appears to me possible, therefore, and even probable, that magnetic action may be communicated to a distance by the action of the intervening particles, in a manner having a relation to the way in which the inductive forces of static electricity are transferred to a distance (1677), the intervening particles assuming for the time more or less of a peculiar condition which (though with a very imperfect idea) I have several times expressed by the term *electro-tonic state* (60, 242, 1114, 1661) I hope it will not be understood that I hold the settled opinion that such is the case I would rather in fact have proved the contrary, namely, that magnetic forces are quite independent of the matter intervening between the inductric and the inducteous bodies, but I cannot get over the difficulty presented by such substances as copper, silver, lead, gold carbon, and even aqueous solutions (201, 213), which though they are known to assume a peculiar state whilst intervening between the bodies

acting and acted upon (1727), no more interfere with the final result than those which have as yet had no peculiarity of condition discovered in them

1730 A remark important to the whole of

prove that the final amount of action on each of the two coils or the two cores A and B (1713, 1719) is equal, yet there is an effect which *may* be consequent on the difference of action of two interposed bodies which it would not show

stances, do not do so in the same time and yet, because of the length of time occupied by a vibration of the needle, this difference may not be visible, both effects rising to their maximum in periods so short as to make no sensible portion of that required for a vibration of the needle, and so exert no visible influence upon it

1731 If the lateral or transverse force of

tween the natures of these two forces (1654, 1664) I do not mean that the powers are independent of each other and might be rendered separately active on the contrary they are probably essentially associated (1654), but it by no means follows that they are of the same nature In common statical induction in conduction, and in electrolyzation, the forces at the opposite extremities of the particles which coincide with the lines of action and have commonly been distinguished by the term electric, are polar, and in the cases of contiguous particles act only to insensible distances, whilst those which are transverse to the direction of these lines, and are called magnetic, are circumferential, act at a distance, and if not through the mediation of the intervening particles have their relations to ordinary matter entirely unlike those of the electrical forces with which they are associated

[1] See *Annales de Chimie* 1833 Vol LI pp 422 428.

1732 To decide the question of the ...

the reach of experiment, and offers a high reward to him who will attempt its settlement

1733 I have already expressed a hope of finding an effect or condition which shall be to statical electricity what magnetic force is to current electricity (1658) If I could have proved to my own satisfaction that magnetic forces extended their influence to a distance by

(1659), or that state so often hinted at as the electro tonic state (1661, 1662), was this related condition of statical electricity

1734 It may be said that the state of *no lateral action* is to static or inductive force the equivalent of *magnetism* to current force, but that can only be upon the view that electric and magnetic action are in their nature essentially different (1664) If they are the same power, the whole difference in the results being the consequence of the difference of *direction*, then the normal or *undeveloped* state of electric force will correspond with the state of *no lateral action* of the magnetic state of the force, the electric current will correspond with the lateral effects commonly called magnetism, but the state of static induction which is between the normal condition and the current will still re-

ized electric, condition, can both have the same lateral relation If magnetism be a separate *and a higher relation of the powers developed*, then perhaps the argument which presses for this third condition of that force would not be so strong

1735 I cannot conclude these general remarks upon the relation of the el ... magnetic forces without expressing ... prise at the results obtained with the ... plate (1721, 1725) The experiments ... flat helices represent one of the simp... of the induction of electrical currents ... the effect, as is well known, consists ... production of a momentary c... the instant when a current in the ... direction begins to pass through ... ing parallel wire, and the

equally brief current in the reverse direction when the determining current is stopped (26) Such being the case, it seems very extraordinary that this induced current which takes place in the helix A when there is only air between A and C (1720) should be equally strong when that air is replaced by an enormous mass of that excellently conducting metal copper (1721) It might have been supposed that this mass would have allowed of the formation and discharge of almost any quantity of currents in it, which the helix C was competent to induce, and so in some degree have diminished if not altogether prevented the effect in A instead of which, though we can hardly doubt that an infinity of currents are formed at the moment in the copper plate, still not the smallest diminution or alteration of the effect in A appears (65) Almost the only way of reconciling this effect with generally received notions is, as it appears to me to admit that magnetic action is communicated by the action of the intervening particles (1729, 1733)

1736 This condition of things, which is very remarkable accords perfectly with the effects observed in solid helices where wires are coiled over wires to the amount of five or six or more layers in succession, no diminution of effect on the outer ones being occasioned by those within

§ 22 *Note on Electrical Excitation*

1737 That the different modes in which electrical excitement takes place will some day or other be reduced under one common law can hardly be doubted though for the present we are bound to admit distinctions It will be a great point gained when these distinctions are, not removed, but understood

1738 The strict relation of the electrical and chemical powers renders the chemical mode of excitement the most instructive of all, and the case of two isolated combining particles is probably the simplest that we possess Here however the action is local, and we still want such a test of electricity as shall apply to it, to cases of current electricity, and also to those of static induction Whenever by virtue of the previously combined condition of some of the acting particles (923) we are enabled, as in the voltaic pile, to expand or convert the local action into a current, then chemical action can be traced through its variations to the production of all the phenomena of tension and the static state, these being in every respect the same as if the electric forces producing them had been developed by friction.

1739 It was Berzelius, I believe, who first spoke of the aptness of certain particles to assume opposite states when in presence of each other (959) Hypothetically we may suppose these states to increase in intensity by increased approximation, or by heat, &c, until at a certain point combination occurs, accompanied by such an arrangement of the forces of the two particles between themselves as is equivalent to a discharge, producing at the same time a particle which is throughout a conductor (1700)

1740 This aptness to assume an excited electrical state (which is probably polar in those forming non conducting matter) appears to be a primary fact, and to partake of the nature of induction (1162), for the particles do not seem capable of retaining their particular state independently of each other (1177) or of matter in the opposite state What appears to be definite about the particles of matter is their assumption of a *particular* state, as the positive or negative, in relation to each other, and not of either one or other indifferently, and also the acquirement of force up to a certain amount

1741 It is easily conceivable that the same force which causes local action between two free particles shall produce current force if one of the particles is previously in combination, forming part of an electrolyte (923, 1738) Thus a particle of zinc, and one of oxygen, when in presence of each other, exert their inductive forces (1740), and these at last rise up to the point of combination If the oxygen be previously in union with hydrogen, it is held so combined by an [illegible] arrangem[illegible] [illegible] the time of [illegible] engaged and related, so w[illegible] the superior relation of the forces between the oxygen and zinc come into play, the induction of the former or oxygen towards the metal cannot be brought on and increased without a corresponding deficiency in its induction towards the hydrogen with which it is in combination (for the amount of force in a particle is considered as definite), and the latter therefore has its force turned towards the oxygen of the next particle of water, thus the effect may be considered as extended to sensible distances, and thrown into the condition of static induction, which being discharged and then removed by the action of other particles produces currents

1742 In the common voltaic battery, the current is occasioned by the tendency of the zinc to take the oxygen of the water from the

hydrogen, the effective action being at the place where the oxygen leaves the previously existing electrolyte But Schœnbein has arranged a battery in which the effective action is at the other extremity of this essential part of the arrangement, namely, where oxygen goes to the electrolyte[1] The first may be considered as a case where the current is put into motion by the abstraction of oxygen from hydrogen, the latter by that of hydrogen from oxygen The direction of the electric current is in both cases the same, when referred to the direction in which the elementary particles of the electro lyte are moving (923, 962), and both are equally in accordance with the hypothetical view of the inductive action of the particles just described (1740)

1743 In such a view of voltaic excitement the action of the particles may be divided into two parts, that which occurs whilst the force in a particle of oxygen is rising towards a particle of zinc acting on it, and falling towards the particle of hydrogen with which it is associated (this being the progressive period of the in-

combines with the zinc The former appears to be that which produces the current, or if there

same character Wollaston endeavoured to refer such excitement to chemical action,[2] but if by chemical action ultimate union of the acting particles is intended, then there are plenty of cases which are opposed to such a view Davy mentions some such, and for my own part I feel no difficulty in admitting other

the first part of the action already described (1743), but in my opinion it cannot give rise to a continuous current unless combination take place, so as to allow other particles to act successively in the same manner, and not even then unless one set of the particles be present as an element of an electrolyte (923, 963), i e mere quiescent contact alone without chemical action does not in such cases produce a *current*

1746 Still it seems very possible that such a

favourably circumstanced being in such close contact as to be short only of that which is consequent upon chemical combination At such moments they may acquire by their mutual induction (1740) and partial discharge to each other, very exalted opposite states, and when, the moment after, they are by the progress of the rub removed from each other's vicinity, they will retain this state if both bodies be insulators, and exhibit them upon their complete separation

1747 All the circumstances attending friction seem to me to favour such a view The irregularities of form and pressure will cause that the particles of the two rubbing surfaces will be at very variable distances, only a few at once being in that very close relation which is probably necessary for the development of the forces, further, those which are nearest at one time will be further removed at another, and

into such speculation before that already advanced has been confirmed or corrected by fit experimental evidence I do not wish it be

supposed [illegible]

[illegible] of a thermo-electric nature conduce to the ultimate effect and there are very probably other causes of electric disturbance influential at the same time, which we have not as yet distinguished

Royal Institution, June, 1838

FIFTEENTH SERIES

§ 23 *Notice of the Character and Direction of the Electric Force of the Gymnotus*

RECEIVED NOVEMBER 15, READ DECEMBER 6, 1838

1749 WONDERFUL as are the laws and phenomena of electricity when made evident to us in inorganic or dead matter their interest can bear scarcely any comparison with that which attaches to the same force when connected with the nervous system and with life, and though the obscurity which for the present surrounds the subject may for the time also veil its importance every advance in our knowledge of this mighty power in relation to inert things, helps to dissipate that obscurity, and to set forth more prominently the surpassing interest of this very high branch of physical philosophy We are indeed but upon the threshold of what we may, without presumption, believe man is permitted to know of this matter, and the many eminent philosophers who have assisted in making this subject known have as is very evident in their writings, felt up to the latest moment that such is the case

1750 The existence of animals able to give the same concussion to the living system as the [illegible]

Walsh, Humboldt, &c &c, it became of growing importance to identify the living power which they possess with that which man can call into action from inert matter, and by him named electricity (265, 351) With the *torpedo* this has been done to perfection, and the direction of the current of force determined by the united and successive labours of Walsh,[1] Cavendish,[2] Galvani,[3] Gardini,[4] Humboldt and Gay-Lussac,[5] Todd,[6] Sir Humphry Davy,[7] Dr Davy,[8] Becquerel,[9] and Matteucci [10]

1751 The gymnotus has also been experimented with for the same purpose, and the investigations of Williamson,[11] Garden,[12] Humboldt [13] Fahlberg,[14] and Guisan,[15] have gone very far in showing the identity of the electric force in this animal with the electricity excited by ordinary means and the two latter philosophers have even obtained the spark

1752 As an animal fitted for the further investigation of this refined branch of science, [illegible]

confinement and capability of being preserved alive and in health for a long period A gymnotus has been kept for several months in activity, whereas Dr Davy could not preserve torpedoes above twelve or fifteen days, and Matteucci was not able out of 116 such fish to keep one living above three days, though every circumstance favourable to [illegible] was attend[illegible] fore bec[illegible] stimulat[illegible]

in procuring some of these fishes, and continually expect to receive either news of them or the animals themselves

1753 Since that time Sir Everard Home has also moved a friend to send some gymnoti over,

[illegible]

7 *Ibid* 1829 p 15
8 *Ibid* 1832 p 259 and 1834 p 531
9 *Traité de l Électricité* IV, 264
10 *Bibliothèque Universelle* 1837 Vol XII 163
11 *Philosophical Transactions* 1775, p 94
12 *Ibid*, 1775 p 102
13 *Personal Narrative* chap xvii
14 *Swedish Transactions* 1801 pp 122 156
15 *De Gymnoto Electrico* Tubingae, 1819
16 *Bibliothèque Universelle* 1837, XII p. 174

which are to be consigned to His Royal Highness our late President, and other gentlemen are also engaged in the same work This spirit induces me to insert in the present communication that part of the letter from Baron Humboldt which I received as an answer to my inquiry of how they were best to be conveyed

tion We lost them so soon at Paris because they were too much fatigued (by experiments) immediately after their arrival MM Norder-

about twenty-seven or twenty-eight inches in

being cooked meat, *not salted*, small fish, or even bread Trial should be made of their strength and the fit kind of nourishment before they are shipped, and those fish only selected already accustomed to their prison I retained

trough, for the gymnotus often springs out of the water These are all the directions that I can give you It is, however, *important* that the animal should not be tormented or fatigued, for it becomes exhausted by frequent electric

hope to institute when the expected supply of animals arrives (1752)

ing, and in this way the animal perhaps obtained some nourishment On the 19th of October it killed and eat *four small fish since then* the blood has been discontinued, and the ani-

month to a week between each His health seemed to improve continually, and it was during this period, between the third and fourth days of experiment, that he began to eat

1757 Beside the hands two kinds of collec- ... The one sort consisted each of a

tended to meet the difficulty presented by the complete immersion of the fish in water, for even when obtaining the spark itself I did not think myself justified in asking for the removal of the animal into air A plate of copper eight

[1] The fish eaten were gudgeons, carp and perch.

inches long by two inches and a half wide, was bent into a saddle shape, that it might pass over the fish, and inclose a certain extent of the back and sides, and a thick copper wire was brazed to it, to convey the electric force to the experimental apparatus a jacket of sheet caoutchouc was put over the saddle, the edges projecting at the bottom and the ends, the ends were made to converge so as to fit in some degree the body of the fish, and the bottom edges were made to spring against any horizontal surface on which the saddles were placed The part of the wire liable to be in the water was covered with caoutchouc.

1759 These conductors being put over the fish, collected power sufficient to produce many electric effects, but when, as in obtaining the spark, every possible advantage was needful, then glass plates were placed at the bottom of the water, and the fish being over them the conductors were put over it until the lower caoutchouc edges rested on the glass, so that the part of the animal within the caoutchouc was thus almost as well insulated as if the gymnotus had been in the air

1760 *Shock* The shock of this animal was very powerful when the hands were placed in a favourable position, i e, one on the body near the head, and the other near the tail, the nearer the hands were together within certain limits the less powerful was the shock The disc conductors (1757) conveyed the shock very well when the hands were wetted and applied in close contact with the cylindrical handles, but scarcely at all if the handles were held in the dry hands in an ordinary way

1761 *Galvanometer* Using the saddle conductors (1758) applied to the anterior and posterior parts of the gymnotus, a galvanometer was readily affected It was not particularly delicate, for zinc and platina plates on the upper and lower surface of the tongue did not cause a permanent deflection of more than 25°, yet when the fish gave a powerful discharge the deflection was as much as 30°, and in one case even 40°. The deflection was constantly in a given direction, the electric current being always from the anterior parts of the animal through the galvanometer wire to the posterior parts The former were therefore for the time externally positive, and the latter negative

1762 *Making a magnet* When a little helix containing twenty-two feet of silked wire wound on a quill was put into the circuit, and an annealed steel needle placed in the helix, the needle became a magnet, and the direction of its polarity in every case indicated a current from the anterior to the posterior parts of the gymnotus through the conductors used

1763 *Chemical decomposition* Polar decomposition of a solution of iodide of potassium was easily obtained Three or four folds of paper moistened in the solution (322) were placed between a platina plate and the end of a wire also of platina, these being respectively connected with the two saddle conductors (1758) Whenever the wire was in conjunction with the conductor at the fore part of the gymnotus iodine appeared at its extremity but when connected with the other conductor, none was evolved at the place on the paper where it before appeared So that here again the direction of the current proved to be the same as that given by the former tests

1764 By this test I compared the middle part of the fish with other portions before and behind it, and found that the conductor A, which being applied to the middle was negative to the conductor B applied to the anterior parts was on the contrary, positive to it when B was applied to places near the tail So that within certain limits the condition of the fish externally at the time of the shock appears to be such that any given part is negative to other parts anterior to it, and positive to such as are behind it.

1765 *Evolution of heat* Using a Harris thermo-electrometer belonging to Mr Gassiot we thought we were able in one case, namely that when the deflection of the galvanometer was 40° (1761), to observe a feeble elevation of temperature I was not observing the instrument myself, and one of those who at first believed they saw the effect now doubts the result [1]

1766 *Spark* The electric spark was obtained thus A good magneto-electric coil, with a core of soft iron wire, had one extremity made fast to the end of one of the saddle collectors (1758) and the other fixed to a new steel file another file was made fast to the end of the other collector One person then rubbed the point of one of these files over the face of the other whilst another person put the collectors over the fish, and endeavoured to excite it to action. By the friction of the files contact was made and broken very frequently, and the object was to catch the moment of the current through the wire and helix, and by breaking contact during the current to make the electricity sensible as a spark.

[1] In more recent experiments of the same kind we could not obtain the effect.

1767 The spark was obtained four times and nearly all who were present saw it That it was not due to the mere attrition of the two piles was shown by its not occurring when the files were rubbed together, independently of the animal Since then I have substituted for

spark was obtained

1768 Such were the general electric phenomena obtained from this gymnotus whilst living and active in his native element On several occasions many of them were obtained together,

tails of experiments relating to the quantity and disposition of the electricity in and about this wonderful animal will not be out of place in this short account of its powers

1770 When the shock is strong it is like that of a large Leyden battery charged to a low degree, or that of a good voltaic battery of perhaps one hundred or more pair of plates, of which the circuit is completed for a moment only I endeavoured to form some idea of the *quantity* of electricity by connecting a large Leyden battery (291) with two brass balls, above three inches in diameter, placed seven inches apart in a tub of water, so that they

found necessary to prevent the easy occurrence of the spark at the ends of the collectors (1758), when they were applied in the water near to the balls as they had been before to the fish

fish is at least equal to the electricity of a Leyden battery of fifteen jars containing 3500 square inches of glass coated on both sides, charged to its highest degree (291) This conclusion respecting the great quantity of elec-

the electrolyzing experiments

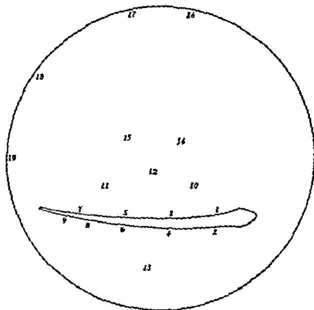
scarcely a sensible interval of time is very important in the considerations which must arise hereafter respecting the origin and excitement of the power in the animal Walsh Humboldt, Gay-Lussac, and Matteucci have remarked the same thing of the torpedo, but in a far more striking degree

surrounds the animal to a considerable distance from its body The shock which is felt,

and momentary as the external one), we cannot

and the depth of water in it three inches and a half, it is supported on dry wooden legs The figures represent the places where the hands or the disc conductors (1757) were applied, and where they are close to the figure of the animal, it implies that contact with the fish was made I will designate different persons by A, B, C, &c, A being the person who excited the fish to action

1774 When one hand was in the water the shock was felt in that hand only, whatever part of the fish it was applied to, it was not very strong, and was only in the part immersed in the water When the hand and part of the arm were in, the shock was felt in all the parts immersed



1775 When *both* hands were in the water at the *same* part of the fish still the shock was comparatively weak, and only in the parts immersed If the hands were on opposite sides, as at 1, 2, or at 3, 4, or 5, 6, or if one was above and the other below at the same part, the effect was the same When the disc collectors were used in these positions no effect was felt by the person holding them (and this ... the observ... w... dis... I ... wer ... the ... p. 18.

and even to the breast of the experimenter, occurred, though another person with a single hand in at any of these places, felt comparatively little The shock could be obtained at parts very near the tail, as at 8, 9 I think it was strongest at about 1 and 8 As the hands were brought nearer together the effect diminished, until being in the same cross plane, it was, as before described, only sensible in the parts immersed (1775).

1777 B placed his hands at 10, 11, at least four inches from the fish, whilst A touched the animal with a glass rod to excite it to action B quickly received a powerful shock In another experiment of a similar kind, as respects the non necessity of touching the fish, several persons received shocks independently of each other, thus A was at 4, 6, B at 10, 11, C at 16, 17, and D at 18, 19, all were shocked at once, A and B very strongly, C and D feebly It is very useful, whilst experimenting with the galvanometer or other instrumental arrangements, for one person to keep his hands in the water at a moderate distance from the animal, that he may know and give information when a discharge has taken place

1778 When B had both hands at 10, 11, or at 14, 15, whilst A had but one hand at 1, or 3, or 6, the *former* felt a strong shock, whilst the *latter* had but a weak one, though in contact with the fish Or if A had both hands in at 1, 2, or 3, 4, or 5, 6, the effect was the same

1779. If A had the hands at 3, 5, B at 14, 15, and C at 16, 17, A received the most powerful shock, B the next powerful, and C the feeblest

1780 When A excited the gymnotus by his hands at 8, 9, whilst B was at 10, 11, the latter had a much stronger shock than the former, though the former touched and excited the animal

1781 A excited the fish by one hand at 3, whilst B had both hands at 10, 11 (or along), and C had the hands at 12, 13 (or across), A had the pricking shock in the immersed hand only (1774), B had a strong shock up the arms C felt but a slight effect in the immersed parts

1782 The experiments I have just described are of such a nature as to require many repetitions before the general results drawn from them can be considered as established, nor do I pretend to say that they are anything more

than indications of the direction of the force It is not at all impossible that the fish may have the power of throwing each of its four

time bring the other side of his body into such a condition that it shall be as a non-conductor in that direction But I think the appearances and results are such as to forbid the supposition that he has any control over the direction of the currents after they have entered the fluid and substances around him

1783 The statements also have reference to the fish when in a straight form, if it assume a bent shape then the lines of force around it vary in their intensity in a manner that may be anticipated theoretically Thus if the hands were applied at 1 7, a feebler shock in the arms would be expected if the animal were curved with that side inwards than if it were straight, because the distance between the parts would be diminished and the intervening water therefore conduct more of the force But with respect to the parts *immersed* or to animals as fish *in the water* between 1 and 7, they would be more powerfully, instead of less powerfully, shocked

1784 It is evident from all the experiments, as well as from simple considerations, that all the water and all the conducting matter around the fish through which a discharge circuit can in any way be completed is filled at the mo-

gymnotus, surrounded equally in all directions by water, these would resemble generally in disposition, the magnetic curves of a magnet having the same straight or curved shape as the animal, i e, provided he in such cases employed as may be expected, his four electric organs at once

midst of the waters its side floating to the light T

crease the force of the shock and the action is evidently exceedingly well suited for that purpose (1783) being in full accordance with the well known laws of the discharge of currents in masses of conducting matter, and though the fish may not always put this artifice in practice, it is very probable he is aware of its ad-

ation soon makes one conscious of many points

are in the most perfect contrast with the inefficient state of things which would exist if the

though a moist one conducts it (1760) so is it

conquered

notus may exert only an equal power, for the

1788 The gymnotus appears to be sensible when he has shocked an animal being conscious of it, probably, by the

pulse he receives, caused by the spasms into which it is thrown When I touched him with my hands, he gave me shock after shock, but when I touched him with glass rods, or the insulated conductors, he gave one or two shocks, felt by others having their hands in at a distance, but then ceased to exert the influence, as *if made aware it had not the desired effect.* Again, when he has been touched with the conductors several times, for experiments on the *galvanometer or other apparatus*, and appears to be languid or indifferent, and not willing to give shocks, yet being touched by the hands, they, by convulsive motion, have informed him that a sensitive thing was present, and he has quickly shown his power and his willingness to astonish the experimenter.

1789 It has been remarked by Geoffroy St Hilaire that the electric organs of the torpedo, gymnotus, and similar fishes, cannot be considered as essentially connected with those which are of high and direct importance to the life of the animal, but to belong rather to the common *teguments, and it has also been found that* such torpedoes as have been deprived of the use of their peculiar organs, have continued the *functions of life quite as well as those in which* they were allowed to remain These, with other considerations, lead me to look at these parts with a hope that they may upon close investigation prove to be a species of natural apparatus, by means of which we may apply the principles of *action and reaction* in the investigation of the nature of the *nervous influence*

1790 The anatomical relation of the nervous system to the electric organ, the evident exhaustion of the nervous energy during the production of electricity in that organ, the apparently equivalent production of electricity in proportion to the quantity of nervous force consumed, the constant direction of the current produced, with its relation to what we may believe to be an equally constant direction of *the nervous energy thrown into action at the* same time, all induce me to believe, that it is not impossible but that, on passing electricity *perforce through the organ, a reaction back upon* the nervous system belonging to it might take place, and that a restoration, to a greater or smaller degree, *of that which the animal expends* in the act of exciting a current, might perhaps be effected We have the analogy in relation to heat and magnetism Seebeck taught us how to commute heat into electricity, and Peltier has more lately given us the strict converse of this, and shown us how to convert the electricity into heat, including both its relation of hot and cold Oersted showed how we were to convert electric into magnetic forces, and I had the delight of adding the other member of the full relation, by reacting back again and converting magnetic into electric forces So perhaps *in these organs, where nature has provided* the apparatus by means of which the animal can exert and convert nervous into electric force, we may be able, possessing *in that point of view* a power far beyond that of the fish itself, to reconvert the electric into the nervous force

1791 This may seem to some a very wild notion, as assuming that the nervous power is in some degree analogous to such powers as heat, electricity, and magnetism I am only assuming it, however, as a reason for making certain experiments, which, according as they give positive or negative results, will regulate further expectation And with respect to the nature of nervous power, that exertion of it which is conveyed along the nerves to the various organs which they excite into action, is not the *direct principle of life, and therefore I see no* natural reason why we should not be allowed in certain cases to *determine* as well as observe its course Many philosophers *think the power is* electricity Priestley put forth this view in 1774 in a very striking and distinct form, both as regards ordinary animals and those which are electric, like the torpedo[1] Dr Wilson Philip considers that the agent in certain nerves is electricity modified by vital action[2] Matteucci thinks that the nervous fluid or energy, in the nerves belonging to the electric organ at least, is electricity[3] MM Prevost and Dumas are of opinion that electricity moves in the nerves belonging to the muscles, and M Prevost adduces a beautiful experiment, in which steel was magnetized, in proof of this view, which, if it should be confirmed by further observation and by other philosophers, is of the utmost consequence to the progress of this high branch of

[1] Priestley on *Air* Vol I p 277 edition of 1774.

[2] Dr Wilson Philip is of opinion that the nerves which excite the muscles and effect the chemical changes of the vital functions, operate by the electric power supplied by the brain and spinal marrow in its effects modified by the vital powers of the living animal because he found as he informs me as early as 1815 that while the vital powers remain all these functions can be as well *performed* by voltaic electricity after the *removal* of the nervous influence as by that influence itself and in the end of that year he presented a paper to the Royal Society which was read at *one of their meetings*, giving an account of the experiments on which this position was founded.

[3] *Bibliothèque Universelle* 1837, Vol. XII. 192.

knowledge [1] Now though I am not as yet convinced by the facts that the nervous fluid is only electricity still I think that the agent in

the natural direction i e from below upwards

reach of experiment

1792 The kind of experiment I am bold

other degrees of force either continuously or intermittingly in the same direction as those he sends forth, restore him his powers and strength more rapidly than if he were left to his natural repose?

1793 Would sending currents through in the contrary direction exhaust the animal rapidly?

organ? Will it do so if the nerves proceeding to the organ or organs be tied? and will it do so after the animal has been so far exhausted by previous shocks as to be unable to throw the organ into action in any or in a similar degree of his own will?

1795 Such are some of the experiments which the conformation and relation of the electric organs of these fishes suggest as being rational in their performance and promising in anticipation Others may not think of them as I do but I can only say for myself that were the means in my power they are the very first I would make

[1] *Ibid* 1837 XII 202 XIV 200

Royal Institution November 9 1838

SIXTEENTH SERIES

§ 24 *On the Source of Power in the Voltaic Pile* ¶ i *Exciting Electrolytes, &c, Being Conductors of Thermo and Feeble Currents* ¶ ii *Inactive Conducting Circles Containing a Fluid or Electrolyte* ¶ iii *Active Circles Excited by Solution of Sulphuret of Potassium, &c*

RECEIVED JANUARY 23 READ FEBRUARY 6 1840

§ 24 *On the Source of Power in the Voltaic Pile*

1796 WHAT is the source of power in a voltaic pile? This question is at present of the utmost importance in the theory and to the development of electrical science The opinions held respecting it are various but by far the most important are the two which respectively find the source of power in contact and in chemical force The question between them touches the first principles of electrical action for the opinions are in such contrast that two men respectively adopting them are thenceforward constrained to differ in every point respecting the probable and intimate nature of the agent or force on which all the phenomena of the voltaic pile depend

1797 The theory of contact is the theory of Volta the great discoverer of the voltaic pile itself and it has been sustained since his day by a host of philosophers amongst whom in recent times rank such men as Pfaff Marianini Fechner Zamboni Matteucci Karsten Bou [illegible]

oped since by Oersted, Becquerel, De la Rive, *Ritchie Pouillet*, Schœnbein and many others, amongst whom Becquerel ought to be distinguished as having contributed, from the first a *continually increasing mass of the strongest* experimental evidence in proof that chemical action always evolves electricity [1] and De la Rive should be named as most clear and constant in his views and most zealous in his production of facts and arguments from the year 1827 to the present time [2]

1798 Examining this question by the results of definite *electro-chemical action* I felt constrained to take part with those who believed the origin of voltaic power to consist in chemical action alone *(875 965) and* ventured a paper on it in April 1834[3] (875, &c) which obtained the especial notice of Marianini [4] The rank of this philosopher, the observation of Fechner,[5] and the conse ...
greater ...
theo ...
exam ...
not n ... error but was anxious to convince myself of the truth of the contact theory for it was evident that if contact electromotive force had any existence it must be a power not merely unlike every other natural power as to the phenomena it could produce but also in the far higher points of limitation definite force and finite production (2065)

1799 *I venture to hope that the experimental* results and arguments which have been thus gathered may be useful to science I fear the detail will be tedious but that is a necessary consequence of the state of the subject The contact theory *has long had possession of men s* minds is sustained by a great weight of authority and for years had almost undisputed sway *in some parts of Europe If it be an error it can* only be rooted out by a great amount of forcible experimental evidence *a fact* sufficiently clear to my mind by the circumstance that De la Rive s papers have not already convinced the workers upon this *subject Hence the reason* why I have thought it needful to add my further testimony to his and that of others entering into detail and multiplying facts in a proportion far beyond any which would have been required for the proof and promulgation of a new *scientific truth (2017) In so doing I may occa*sionally be only enlarging yet then I hope strengthening what others and especially De la Rive have done

1800 It will tend to clear the question *if the* various views of contact are first stated Volta s theory is, that the simple contact of conduct*ing bodies causes electricity to be developed* at the point of contact without any change in nature of the bodies themselves and that though such *conductors* as water *and aqueous* fluids have this property yet the degree in which they possess it is unworthy of consideration in comparison with the degree to which it rises amongst the metals [6] The present views of the Italian and German contact *philosophers* are I believe generally the same except that occasionally more importance is attached to the *contact of the imperfect conductors with the* metals Thus Zamboni (in 1837) considers the metallic contact as the most powerful *source of* electricity and not that of the *metals* with the fluids [7] but Karsten holding the contact theory transfers the *electromotive force to the con*tact of the fluids with the solid conductors [8] Marianini holds the same view of the *principle of contact with this addition that actual con*tact is not required to the exertion of the exciting force, but that the two approximated dissimilar conductors may affect each other s state when separated by sensible intervals of the *thousandth of a line and more air intervening* [9]

1801 De la Rive, on the contrary contends for simple and strict chemical action and as far as I am aware admits *of no current in the* voltaic pile that is not conjoined with and dependent upon a complete *chemical effect* That admirable electrician Becquerel though expressing himself with great caution *seems to admit the possibility of chemical attractions* being able to produce electrical currents when they are not strong enough to overcome the force of cohesion and so terminate in combination [10] Schœnbein states that a current may be produced *by a tendency to chemical action* ...

[1] A D 1824 &c *Annales de Chimie* 1824 XXV 405 1827 XXXV 113 1831 XLVI 265 276 337 XLVII 113 XLIX 131

[2] *Ibid* 1828 XXXVII 225 XXXIX 297 1836, LXII 147 or *Mémoires de Genève* 1829 IV 285 1832 VI 149 1835 VII

[3] *Philosophical Transactions* 1834 p 425

[4] *Memorie della Società Italiana in Modena* 1837 XXI p 205

[5] *Philosophical Magazine* 1838 XIII 205 or *Poggendorf s Annalen* XLII p 481 *Fechner refers* also to Pfaff s reply to my paper I never cease to regret that the German is a sealed language to me

[6] *Annales de Chimie* 1801 XL p 225

[7] *Bibliothèque Universelle* 1836 V 387 1837 VIII 189

[8] *L Institut* No 150

[9] *Mem della Soc Ital in Modena* 1837 XXI 232 237

[10] *Annales de Chimie* 1835 LX 171 and *Traité de l Électricité* I pp 253 258

that substances which have a tendency to unite chemically may produce a current, though that tendency is not followed up by the actual combination of the substances [1] In these cases the

[illegible]

cited the current or was the cause of it, but that chemical changes supplied the current For myself I am at present of the opinion which De la Rive holds, and do not think that, in the voltaic pile, mere contact does anything in the excitation of the current, except as it is preparatory to and ends in, complete chemical action (1741, 1745)

1802 Thus the views of contact vary, and it may be said that they pass gradually from one to another, even to the extent of including chemical action but the two extremes appear to me irreconcilable in principle under any shape, they are as follows The contact theory assumes that when two different bodies being conductors of electricity are in contact, there is

[illegible]

has caused, but discharge their electricities to the masses respectively behind them (2067)

[illegible]

2069)

1803 The chemical theory assumes, that at the place of action, the particles which are in contact act chemically upon each other and are able, under the circumstances, to throw more or less of the acting force into a dynamic form (947, 996, 1120) that in the most favourable circumstances, the whole is converted into dynamic force (1000) that then the amount of current force produced is an exact equivalent of the original chemical force employed and that in no case (in the voltaic pile) can any electric current be produced without the active exertion and consumption of an equal amount of chemical force, ending in a given amount of chemical change

1804 Marianini s paper[2] was to me a great motive for re-examining the subject, but the course I have taken was not so much for the purpose of answering particular objections, as for the procuring evidence whether relating to controverted points or not, which should be satisfactory to my own mind, open to receive either one theory or the other This paper, therefore is not controversial, but contains further facts and proofs of the truth of De la Rive s views The cases Marianini puts are of extreme interest, and all his objections must, one day be answered, when numerical results both as to

[illegible]

power of an opposed acting source of a current

[illegible]

1806 With respect to the [illegible] cause of the spark before contact,[5] Marianini admits the spark, but I give it up altogether Jacobi s paper[6] convinces me I was in error as to *that proof* of the existence of a state of tension

[1] *Philosophical Magazine* 1838 XII 227 311 314 also *Bibliothèque Universelle* 1838 XIV, 155 395

[2] *Memorie della Società Italiana in Modena* 1827, XXI p 205

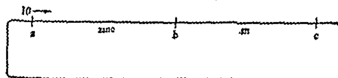
[3] *Ibid* 1827 XXI p 217

[4] *Ibid* p 217

[5] *Ibid* p 2?5.

[6] *Philosophical Magazine* 1838 XIII 401

PLATE XII



Copper
Fig 1

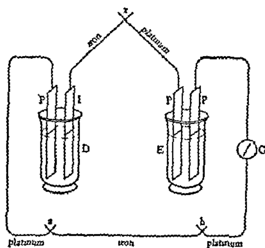


Fig 2

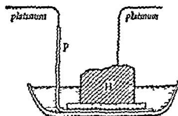
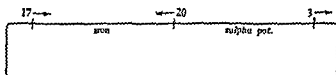
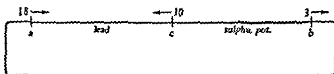


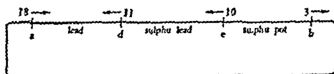
Fig 3



platinum
Fig 4



platinum
Fig 5



platinum
Fig 6

in the metals before contact (915, 956). I need not therefore do more at present than withdraw my own observations

1807. I now proceed to address myself to the

we have to account for, but such as indicates a force of extreme power, requiring, therefore, that the cause assigned should bear some proportion, both in intensity and quantity, to the effects produced

1808 The investigations have all been made by aid of currents and the galvanometer, for it seemed that such an instrument and such a course were best suited to an examination of the electricity of the voltaic pile The electrometer is no doubt a most important instrument, but the philosophers who do use it are not of accord in respect to the safety and delicacy of its results And even if the few indications as yet given by the electrometer be accepted as correct, they are far too general to settle the question of, whether contact or chemical action is the exciting force in the voltaic battery. To apply that instrument closely and render it of any force in supplying affirmative arguments to either theory, it would be necessary to construct a table of contacts,

potassium, its contact force at *b*′ might be

large assumption, and that the theory may agree with the facts is necessary still it is, I believe, only an assumption, for I am not aware of any data, independent of the theory in

metals, or if they do exert such a power, then it is with this most important difference, that the forces are not subject to the same law of com-

support.

1811. Guided by this opinion, and with a view to ascertain what is, in an active circle, effected by contact and what by chemical action, I endeavoured to find some bodies in this latter class (1810) which should be without chemical action on the metals employed, so as to exclude that cause of a current, and yet such

pose, I sought for such, and fortunately soon found them.

¶ 1. *Exciting Electrolytes, &c, Being Conductors of Thermo and Feeble Currents*

1812 *Sulphuret of potassium* This substance and its solution were prepared as follows Equal weights of caustic potash (*potassa fusa*) and sulphur were mixed with and heated gradually in a Florence flask, till the whole had fused and united, and the sulphur in excess began to sublime It was then cooled and dissolved in water, so as to form a strong solution, which by standing became quite clear.

1813 A portion of this solution was included

causing the galvanometer needle to be permanently deflected, occasionally as much as 80° Even the small difference of temperature occasioned by touching the Seebeck element with the finger, produced a very sensible current through the electrolyte When in place of the antimony bismuth combination mere wires of *copper and platinum*, or *iron and platinum* were used, the application of the spirit lamp to the junction of these metals produced a thermo current which instantly travelled round the circuit

1814 Thus this electrolyte will as to h conducting power full t rem ved

ɛ

ƚ ‥y plati-

n

‥ *Nitrous acid* Yellow anhydrous nitrous acid, made by distilling dry nitrate of lead, being put into a glass tube and included in a circuit with the antimony bismuth arrangement and the galvanometer, gave no indication of the passage of the thermo current, though the immersed electrodes consisted each of about four inches in length of moderately thick platinum wire, and were not above a quarter of an inch apart

1816 A portion of this acid was mixed with nearly its volume of pure water, the resulting action caused depression of temperature, the evolution of some nitrous gas, the formation of some nitric acid, and a dark green fluid was produced This was now such an excellent conductor of electricity, that almost the feeblest current could pass it That produced by Seebeck's circle was sensible when only one-eighth of an inch in length of the platinum wires dipped in the acid When a couple of inches of each electrode was in the fluid, the conduction was so good, that it made very little difference at the galvanometer whether the platinum wires touched each other in the fluid, or were a quarter of an inch apart [1]

1817 *Nitric acid* Some pure nitric acid was boiled to drive off all the nitrous acid and ‥ cooled. Being includ‥ num ‥

l ‥ temperature was a‥ ‥est, was scarcely perceptible at the galvanometer

[1] De la Rive has pointed out the facility with which an electric current passes between platinum and nitrous acid *Annales de Chimie*, 1828, XXXVII 278.

1818 On using a pale yellow acid, otherwise pure, it was found to possess rather more conducting power than the former On employing a red nitric acid, *it was found to conduct the thermo current very well On adding some of the green nitrous acid (1816) to the colourless* nitric acid, the mixture acquired high conducting powers Hence it is evident that nitric acid is not a good conductor when pure, but that the presence of nitrous acid in it (conjointly probably with water), gives it this power in a very high degree amongst electrolytes [*] A very red strong nitric acid, and a weak green acid (consisting of one vol strong nitric acid and two vols of water, which had been rendered green by the action of the negative platinum electrode of a voltaic battery), were both such excellent conductors that the thermo current could pass across *five separate portions of them connected by platinum plates, with so little retardation that I believe twenty interruptions would not have stopped this feeble current*

1819 *Sulphuric acid* Strong oil of vitriol, when between platinum electrodes (1813), conducted the antimony bismuth thermo current sensibly, but feebly A mixture of two volumes acid and one volume water conducted much better, but not nearly so well as the two former electrolytes (1814, 1816) A mixture of one volume of oil of vitriol and two volumes saturated solution of sulphate of copper conducted this feeble current very fairly

Potassa A strong solution of caustic potassa, between platinum plates, conducted the thermo current sensibly, but very feebly

1820 I will take the liberty of describing here, as the most convenient place, other results relating to the conducting power of bodies, which will be *required hereafter in these investigations* Galena, *yellow sulphuret of iron, arsenical pyrites, native sulphuret of copper and iron, native gray artificial sulphuret of copper, sulphurets of bismuth, iron, and copper, globules of oxide of burnt iron, oxide of iron by heat or scale oxide, conducted the thermo current very well Native peroxide of manganese and peroxide of lead conducted it* moderately well

1821 The following are bodies, *in some respect* analogous in nature and composition which did not sensibly conduct this weak current when the contact surfaces were small—

[*] Schœnbein's experiments on a compound of nitric and nitrous acids will probably bear upon and illustrate this subject. *Bibliothèque Universelle*, 1837, X, 406.

artificial gray sulphuret of tin, blende, cinna-

This is the case with the solution of sulphuret of potassium (1813) and the nitrous acid (1816), for the great amount of this power The perox-

powerful one from a voltaic battery This circumstance made me especially anxious to verify the point with the peroxide of lead I therefore prepared some from red lead by the action of successive portions of nitric acid, then boiled

had been removed, after which it was well and perfectly dried Still, when a heap of it in powder, and consequently in very imperfect contact throughout its own mass, was pressed between two plates of platinum and so brought into the thermo-electric circuit (1813), the current was found to pass readily

¶ ii *Inactive Conducting Circles Containing a Fluid or Electrolyte*

1823 De la Rive has already quoted the case of potash, iron and platina,[1] to show that where there was no chemical action there was no current My object is to increase the number of such cases, to use other fluids than potash, and such as have good conducting power for weak currents, to use also strong and weak solutions, and thus to accumulate the conjoint experimental and argumentative evidence by which the great question must finally be decided

1824 I first used the sulphuret of potassium as an *electrolyte of good conducting power*, but chemically inactive (1811) when associated with iron and platinum in a circuit The arrangement is given in Pl XII, *Fig 2*, where D, E represent two test-glasses containing the strong solution of sulphuret of potassium (1812), and also four metallic plates, about 0 5 of an

wires, as in *Fig 2*, a galvanometer being intro-

duced at G In this arrangement there were three metallic contacts of platinum and iron,

pared with either the difference of *a* and *b* when one is warmer than the other, or with itself when in a heated or cooled state (1830), or with the force of chemical action when any body capable of such action is introduced there (1831)

1825 When this arrangement is completed and in order, there is absolutely no current circulating through it, and the galvanometer-needle rests at 0°, yet is the whole circuit open to a very feeble current, for a difference of temperature at any one of the junctions *a*, *b*, or *x*, causes a corresponding thermo current, which is instantly detected by the galvanometer, the needle standing permanently at 30° or 40°, or even 50°

1826 But to obtain this proper and normal state, it is necessary that certain precautions be attended to In the first place, if the circuit be complete in every part except for the immersion of the iron and platinum plates into the cup D, then, upon their introduction, a current will be produced directed from the platinum (which appears to be positive) through the solution to the iron, this will continue perhaps five or ten minutes, or if the iron has been carelessly cleaned, for several hours, it is due to an action of the sulphuretted solution on *oxide of iron*, and not to any effect on the metallic iron and when it has ceased, the disturbing cause may be considered as exhausted The experimental proofs of the truth of this explanation, I will quote hereafter (2049)

1827 Another precaution relates to the effect of accidental movements of the plates in the solution If two platinum plates be put into a solution of this sulphuret of potassium, and the circuit be then completed, including a galvanometer, the arrangement, if perfect, will show no current, but if one of the plates be

other metal or substance not acted on by the sulphuret, the same effect will be produced In these cases, the current is due to the change

[1] *Philosophical Magazine* 1837, XI 275

* Marianini observed effects of th[illegible] by exposure to the air of one [illegible] nitric acid *Annales de Chimie* [illegible], XL[illegible]

wrought by the air on the film of sulphuretted solution adhering to the removed plate,[1] but a far less cause than this will produce a current, for if one of the platinum plates be removed, washed well, dried, and even heated it will, on its re-introduction almost certainly exhibit the negative state for a second or two

1828 These or other disturbing causes appear the greater in these experiments in consequence of the excellent conducting power of the solution used but they do not occur if care be taken to avoid any disturbance of the plates or the solution, and then as before said, the whole acquires a normal and perfectly inactive state

1829 Here then is an arrangement in which the contact of platinum and iron at x is at liberty to produce any effect which such a contact may have the power of producing, and yet what *is* the consequence? absolutely nothing This is not because the electrolyte is so bad a conductor that a current of contact cannot pass, for currents far feebler than this is assumed to be, pass readily (1813), and the electrolyte employed is vastly superior in conducting power to those which are commonly used in voltaic batteries or circles, in which the current is still assumed to be dependent upon contact The simple conclusion to which the experiment should lead is, in my opinion, that the contact of iron and platinum is absolutely without any electromotive force (1835, 1859, 1889)

1830 If the contact be made really active and effective, according to the beautiful discovery of Seebeck, by making its temperature different to that of the other parts of the circuit, then its power of generating a current is shown (1824) This enables us to compare the supposed power of the mere contact with that of a thermo contact, and we find that the latter comes out as infinitely greater than the former, for the former is nothing. The same comparison of mere contact and thermo contact may be made by contrasting the effect of the contact c at common temperatures, with either the contact at a or at b, either heated or cooled Very moderate changes of temperature at these places produce instantly the corresponding current, but the mere contact at x does nothing

1831 So also I believe that a true and philosophic and even rigid comparison may be made at x, between the assumed effect of mere contact and that of chemical action For if the metals at x be separated, and a piece of paper moistened in dilute acid, or a solution of salt, or if only the tongue or a wet finger be applied there, then a current is caused *stronger by far* than the *thermo currents before produced* (1830), passing from the iron through the introduced acid or other active fluid to the platinum This is a case of current from chemical action without any metallic contact in the circuit on which the effect can for a moment be supposed to depend (879), it is even a case where metallic contact is changed for chemical action, with the result, that where contact is found to be quite ineffectual, chemical action is very energetic in producing a current.

1832 It is of course quite unnecessary to say that the same experimental comparisons may be made at either of the other contacts a or b.

1833 Admitting for the moment that the arrangement proves that the contact of platinum and iron at x has no electromotive force (1835 1859), then it follows also that the contact of either platinum or iron with any other metal has no such force For if another metal as zinc, be interposed between the iron and platinum at x (Pl XII, *Fig 2*), no current is produced and yet the test application of a little heat at a or b, will show by the corresponding current that the circuit being complete will conduct any current that may tend to pass Now that the contacts of zinc with iron and with platinum are of equal electromotive force, is not for a moment admitted by those who support the theory of contact activity, we *ought* therefore to have a resulting action equal to the differences of the two forces, producing a certain current No such current is produced, and I conceive, with the admission above, that such a result proves that the contacts *iron-zinc* and *platinum-zinc* are entirely without electromotive force

1834 Gold, silver, potassium, and copper were introduced at x with the like negative effect and so no doubt might every other metal, even according to the relation admitted amongst the metals by the supporters of the contact theory (1809). The same negative result followed upon the introduction of many other conducting bodies at the same place, as, for instance, those already mentioned as easily conducting the thermo current (1820), and the effect proves, I think, that the contact of any of these with either iron or platinum is utterly ineffective as a source of electromotive force

[1] Becquerel long since referred to the effect of such exposure of a plate dipped in certain solutions, to the air Generally the plate so exposed became positive on re-immersion *Annales de Chimie* 1824, XXV, 405

mental results and resume these points here after (1859 1889)

1836 The experiment was now repeated with the substitution of a bar of *nickel* for that of iron (Pl XII *Fig 2*) (1824) all other things rema ning the same[2] The c rcuit was again found to be a good conductor of a feeble ther mo current but utterly inefficient as a voltaic c rcuit when all was at the same temperature and due precaut ons taken (2051) The intro duction of metals at the contact x was as inef fect ve as bef

obtained and if the reasoning then urged was good it will now follow that the contact of platinum and nickel w th each other or of either with any of the different metals or solid conductors introduced at x is ent rely without electromotive force[3]

See Fechner s words *Philosophical Magaz ne*

1837 Many other pairs of metals were com

those already given with the combinat ons of platinum and iron

1838 It is necessary that due precaut on be

plates of the *same metal* into the solut on with out causing a deflection but this generally goes off very quickly and then the arrangement may be used for the invest gat on (1826) Sometimes there is a feeble but rather permanent deflect on of the needle thus when plati num and palladium were the metals the first effect fell and left a current able to deflect the galvanometer needle 3° ind cating tl e plati num to be pos tive to the pallad um This effect of 3° however is almost nothing compared to what a mere thermo current can cause the lat-

mineral or other substance to be compared with the platinum the fluid being of such

depth that only part of that substance was in it, the rest being clean and dry, on this portion the platinum wire, which completed the circuit, rested The arrangement of this part of the circuit is given in section at Pl XII, *Fig 8*, where H represents a piece of galena to be compared with the platinum P

1840 In this way galena, compact yellow copper pyrites, yellow iron pyrites, and globules of oxide of burnt iron, were compared with platinum (the solution of sulphuret of potassium being the electrolyte used in the circuit), and with the same results as were before obtained with metals (1829, 1833)

1841 Experiments hereafter to be described gave arrangements in which, with the same electrolyte, sulphuret of lead was compared with gold, palladium iron, nickel, and bismuth (1885, 1886) also sulphuret of bismuth with platinum, gold, palladium, iron, nickel, lead, and sulphuret of lead (1894), and always with the same result Where no chemical action occurred there no current was formed although the circuit remained an excellent conductor, and the contact existed by which, it is assumed in the contact theory, such a current should be produced

1842 Instead of the strong solution, a dilute solution of the yellow sulphuret of potassium consisting of one volume of strong solution (1812) and ten volumes of water, was used Plates of platinum and iron were arranged in this fluid as before (1824) at first the iron was negative (2049) but in ten minutes it was neutral, and the needle at 0°[1] Then a weak chemical current excited at x (1831) easily passed and even a thermo current (1830) was able to show its effects at the needle Thus a strong or a weak solution of this electrolyte showed the same phenomena By diluting the solution still further, a fluid could be obtained in which the iron was, after the first effect, permanently but feebly positive On allowing time, however, it was found that in all such cases black sulphuret formed here and there on the iron Rusted iron was negative to platinum (2049) in this very weak solution, which by direct chemical action could render metallic iron positive

1843 In all the preceding experiments the electrolyte used has been the sulphuret of potassium solution, but I now changed this for another, very different in its nature, namely the *green nitrous acid* (1816), which has already been shown to be an excellent conductor of electricity. Iron and platinum were the metals employed, both being in the form of wires The vessel in which they were immersed was a tube like that formerly described (1815), in other respects the arrangement was the same in principle as those already used (1824, 1836) The first effect was the production of a current, the iron being positive in the acid to the platina, but this *quickly ceased*, and the galvanometer needle came to 0° In this state, however, the circuit could not in all things be compared with the one having the solution of sulphuret of potassium for its electrolyte (1824), for although it could conduct the thermo current of antimony and bismuth in a certain degree, yet that degree was very small compared to the power possessed by the former arrangement or to that of a circle in which the nitrous acid was between two platinum plates (1816) This remarkable retardation is consequent upon the assumption by the iron of that peculiar state which Schœnbein has so well described and illustrated by his numerous experiments and investigations But though it must be admitted that the iron in contact with the acid is in a peculiar state (1951, 2001, 2033), yet it is also evident that a circuit consisting of platinum, iron, peculiar iron, and nitrous acid, does not cause a current though it have sufficient conducting power to carry a thermo current

1844 But if the contact of platinum and iron has an electromotive force, why does it not produce a current? The application of heat (1830), or of a little chemical action (1831) at the place of contact does produce a current, and in the latter case a strong one Or if any other of the contacts in the arrangement can produce a current, why is not that shown by some corresponding effect? The only answers are to say that the peculiar iron has the same electromotive properties and relations as platinum, or that the nitrous acid is included under the same law with the metals (1809, 1835), and so the sum of the effects of all the contacts in the circuit is nought, or an exact balance of forces That the iron is like the platinum in having no electromotive force at its contacts without chemical action, I believe, but that it is unlike it in its electrical relations, is evident from the difference between the two in strong nitric acid, as well as in weak acid from their difference in the power of transmitting electric

[1] Care was taken in these and the former similar cases to discharge the platinum surface of any reacting force it might acquire from the action of the previous current, by separating it from the other metals and touching it in the liquid for an instant with another platinum plate.

currents to either nitric acid or sulphuret of potassium, which is very great and also by other differences That the nitrous acid is, as to the power of its contacts, to be separated from other electrolytes and classed with the metals in what is with them only an assumption, is a gratuitous mode of explaining the difficulty, which will come into consideration, with the case of sulphuret of potassium, here after (1835, 1859, 1889, 2060)

1845 To the electro-chemical philosopher, the case is only another of the many strong instances, showing that where chemical action is absent in the voltaic circuit, there no current can be formed, and that whether solution of sulphuret of potassium or nitrous acid be the electrolyte or connecting fluid used, still the results are the same, and contact is shown to be inefficacious as an active electromotive con dition

1846 I need not say that the introduction of different metals between the iron and platinum at their point of contact produced no difference in the results (1833, 1834) and caused no current, and I have said that heat and chemical action applied there produced their corresponding effects But these parallels in action and non action show the identity in nature of this circuit (notwithstanding the production of the surface of peculiar iron on that metal), and that with solution of sulphu ret of potassium so that all the conclusions drawn from it apply here and if that case

gree positive, and then immediately neutral This circuit, then, like the former, gave no current at common temperatures, but it differed

stance was solution of sulphuret of potassium

1848 In using nitrous acid it is necessary that certain precautions be taken, founded on the following effect If a circuit be made with the green nitrous acid, platinum wires and a galvanometer, in a few seconds all traces of a current due to first disturbances will disappear but if one wire be raised into the air and instantly returned to its first position, a current is formed, and that wire is negative across the electrolyte to the other If one wire be dipped only a small distance into the acid, as for instance one fourth

(1037) I may

ment

one half of the permanent current can be overcome by a counter thermo current of bismuth and antimony Thus a sort of comparison is established between a thermo current on the one hand, and a current due to the joint effects of chemical action on iron and contact of iron and platinum on the other Now considering the admitted weakness of a thermo current, it may be judged what the strength of that part of the second current due to contact can, at the utmost, be, and how little it is able to account for the strong currents produced by ordinary voltaic combinations

1851 If for a clean iron wire one oxidized in the flame of a spirit-lamp be used, being associated with platinum in pure strong nitric acid, there is a feeble current, the oxide of iron being positive to the platinum, and the facts mainly as with iron But the further advantage is obtained of comparing the contact of strong and weak acid with this oxidized wire If one volume of the strong acid and four volumes of water be mixed, this solution may be used, and there is even less deflection than with the strong acid the iron side is now not sensibly active, except the most delicate means be used to observe the current. Yet in both cases if a chemical action be introduced in place of the contact, the resulting current passes well, and even a thermo current can be made to show itself as more powerful than any due to contact.

1852 In these cases it is safest to put the whole of the oxidized iron under the surface and connect it in the circle by touching it with a platinum wire, for if the oxidized iron be continued through from the acid to the air, it is almost certain to suffer from the joint action of the acid and air at their surface of contact

1853 I proceeded to use a fluid differing from any of the former this was solution of potassa, which has already been employed by De la Rive (1823) with iron and platina, and which when strong has been found to be a substance conducting so well, that even a thermo current could pass it (1819), and therefore fully sufficient to show a contact current, if any such exists

1854 Yet when a strong solution of this substance was arranged with silver and platinum (bodies differing sufficiently from each other when connected by nitric or muriatic acid), as in the former cases, a very feeble current was produced, and the galvanometer needle stood nearly at zero The contact of these metals therefore did not appear to produce a sensible current, and, as I fully believe, because no electromotive power exists in such contact When that contact was exchanged for a very feeble chemical action, namely, that produced by interposing a little piece of paper moistened in dilute nitric acid (1831), a current was the result So here, as in the many former cases, the arrangement with a little chemical action and no metallic contact produces a current, but that without the chemical action and with the metallic contact produces none

1855 Iron or nickel associated with platinum in this strong solution of potassa was positive The force of the produced current soon fell, and after an hour or so was very small Then annulling the metallic contact at *x* (Pl XII, *Fig 2*), and substituting a feeble chemical action there, as of dilute nitric acid, the current established by the latter would pass and show itself Thus the cases are parallel to those before mentioned (1849, &c), and show how little contact alone could do, since the effect of the conjoint contact of iron and platinum and chemical action of potash and iron were very small as compared with the contrasted chemical action of the dilute nitric acid

1856 Instead of a strong solution of potassa, a much weaker one consisting of one volume of strong solution and six volumes of water was used, but the results with the silver and platinum were the same no current was produced by the metallic contact as long as that only was left for exciting cause, but on substituting a little chemical action in its place (1831), the current was immediately produced

1857 Iron and nickel with platinum in the weak solution also produced similar results except that the positive state of these metals was rather more permanent than with the strong solution Still it was so small as to be out of all proportion to what was to be expected according to the contact theory

1858 Thus these different contacts of metals and other well-conducting solid bodies prove utterly inefficient in producing a current as well when solution of potassa is the third or fluid body in the circuit, as when that third body is either solution of sulphuret of potassium, or hydrated nitrous acid, or nitric acid, or mixed nitric and nitrous acids Further, all the arguments respecting the inefficacy of the contacts of bodies interposed at the junction of the two principal solid substances, which were advanced in the case of the sulphuret of potassium solution (1833), apply here with potassa as they do indeed in every case of a conducting circuit

anxiously sought for such a case, but cannot find one (1798)

tact theory utterly defenceless and without foundation

1860 A supporter of the contact theory may say that the various conducting electrolytes used in the previous experiments are like the metals, i e , that they have an electromotive

in a complete circle, the sum of the forces is 0 (1809) The actions at the contacts are tense electromotive actions, but balanced and so no current is produced But what experiment is there to support this statement? where are

ence between metals and liquid conductors

why should the solution of sulphuret of potassium be an exception? it is quite unlike the metals it does not appear to conduct without decomposition, it is an excellent electrolyte, and an excellent *exciting* electrolyte in proper cases (1880), producing most powerful currents when

1862 But it is not with the sulphuret of potassium alone that this freedom must be al-

being of the class of electrolytes and yet ex-

how will they meet the case of weak nitric acid which is not similar in its action on iron to strong nitric acid (1977), but can produce a powerful current?

1863 The chemical philosopher is embarrassed by none of these difficulties for he first, by a simple direct experiment, ascertains whether any of the two given substances in the circuit are active chemically on each other If

he expects and finds the correspond-

and solution of sulphuret of potassium there is no current, but for iron substitute zinc, and

contacts which are

to form conducting (but chemically inactive) circuits (1867, &c) If the solution of sulphuret of potassium is to be classed with the metals as to its action in the experiments I have quoted (1825, &c), then, how comes it to act quite unlike them, and with a power equal to the *best* of the other class, in the new cases of zinc, copper, silver, &c (1882, 1885, &c)?

1865 This difficulty, as I conceive, must be met, on the part of the contact theorists, by a new assumption, namely, that this fluid sometimes acts as the best of the metals, or first class of conductors, and *sometimes as the best of* the electrolytes or second class But surely this would be far too loose a method of philosophizing in an experimental science (1889), and further, it is most unfortunate for such an assumption, that this second condition or relation of it never comes on by itself, so as to give us a pure case of a current from contact alone, it never comes on *without* that chemical action to which the chemist so simply refers all the current which is then produced

1866 It is unnecessary for me to say that the same argument applies with equal force to the cases where nitrous acid, nitric acid, and solution of potash are used, and it is supported with equal strength by the results which they have given (1843, 1849, 1853).

1867 It may be thought that it was quite unnecessary, but in my desire to establish contact electromotive force, to do which I was at one time very anxious, I made many circuits of three substances, including a galvanometer, all being conductors, with the hope of finding an arrangement, which, without chemical action, should produce a current The number and variety of these experiments may be understood from the following summary in which metals, plumbago, sulphurets and oxides, all being conductors even of a thermo current, were thus combined in various ways

1 Platinum
2 Iron
3 Zinc
4 Copper
5 Plumbago
6 Scale oxide of iron
7 Native peroxide of manganese
8 Native gray sulphuret of copper
9 Native iron pyrites
10 Native copper pyrites
11 Galena
12 Artificial sulphuret of copper
13 Artificial sulphuret of iron
14 Artificial sulphuret of bismuth

1 and 2 with 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, in turn
1 and 3 with 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
1 and 5 with 6, 7, 8, 9, 10, 11, 12, 13, 14
3 and 6 with 7, 8, 9, 10, 11, 12, 13, 14
4 and 5 with 6, 7, 8, 9, 10, 11, 12, 13, 14
4 and 6 with 7, 8, 9, 10, 11, 12, 13, 14
4 and 7 with 8, 9, 10, 11, 12, 13, 14
4 and 8 with 9, 10, 11, 12 13, 14
4 and 9 with 10, 11, 12, 13, 14
4 and 10 with 11, 12, 13, 14
4 and 11 with 12, 13, 14
4 and 12 with 13, 14
4 and 13 with 14
1 and 4 with 12

1868 Marianini states from experiment that copper is positive to sulphuret of copper[1] with the Voltaists, according to the same philosopher, sulphuret of copper is positive to iron (1878), and with them also iron is positive to copper These three bodies therefore ought to give a most powerful circle but on the contrary, whatever sulphuret of copper I have used, I have found not the slightest effect from such an arrangement

1869 As peroxide of lead is a body causing a powerful current in solution of sulphuret of potassium, and indeed in every case of a circuit where it can give up part of its oxygen, I thought it reasonable to expect that its contact with metals would produce a current, if contact ever could A part of that which had been prepared (1822), was therefore well dried, which is quite essential in these cases, and formed into the following combinations

Platinum	Zinc	Peroxide of lead
Platinum	Lead	Peroxide of lead
Platinum	Cadmium	Peroxide of lead
Platinum	Iron	Peroxide of lead

Of these varied combinations, not one gave the least signs of a current, provided differences of temperature were excluded, though in every case the circle formed was, as to conducting power, perfect for the purpose, i e, able to conduct even a very weak thermo current

1870 In the contact theory it is not therefore the metals alone that must be assumed to have their contact *forces* so balanced as to produce, in any circle of them, an effect amounting to nothing (1809), but all solid bodies that are able to conduct, whether they be *forms of* carbon, or oxides, or sulphurets, must be included in the same category. So also must the electrolytes already referred to, namely, the solutions of sulphuret of potassium and potash,

[1] *Memorie della Società Italiana in Modena* 1827, XXI, 224

and nitrous and nitric acids, in every case where they do not act chemically In fact *all conductors* that do not act chemically in the circuit must be assumed, by the contact theory, to be in this condition, until a case of voltaic current without chemical action is produced (1808)

1871 Then, even admitting that the results obtained by Volta and his followers with the electrometer prove that mere contact has an electromotive force and can produce an effect surely all experience with contact alone goes to show that the electromotive forces in a circuit are always balanced How else is it likely that the above-named most varied substances should be found to agree in this respect? unless indeed it be, as I believe, that all substances agree in this of having no such power at all If so, then where is the source of power which can account by the theory of contact for the current in the voltaic pile? If they are not balanced then where is the sufficient case of contact alone producing a current? or where are the numerical data which indicate that such a case can be (1808, 1868)? The contact philosophers are bound to produce, not a case where the current

data of such distinctness and importance as may be worthy of opposition to the numerous cases produced by the chemical philosopher (1892), for without them the contact theory as applied to the pile appears to me to have *no* support, and, as it asserts contact electromotive force even *with* the balanced condition, to be almost without foundation

1872 To avoid these and similar conclusions, the contact theory must bend about in the most particular and irregular way Thus the contact of solution of sulphuret of potassium with iron must be considered as balanced by the joint

formed by the chemical action, then the current

an equilibrium condition of the contacts in the circle.

1873 So also with this sulphuretted solution and with potassa, dilution must, by the theory, be admitted as producing *no change* in the character of the contact force but with nitric acid,

with zinc and platinum for instance, must be

their nature

1874 Every case of a current is obliged to be met, on the part of the contact advocates, by assuming powers at the points of contact, in *the particular case*, of such proportionate strengths as will consist with the results obtained and the theory is made to bend about (1956, 1992 2006, 2014 2063) having no general relation for the acids or alkalies or other

chemical action, and in those associated with chemical action, it bends about to suit the real results these contortions being exactly parallel to the variations which the pure chemical force, by experiment, indicates

1875 In the midst of all this, how simply does the chemical theory meet, include, combine and even predict, the numerous experimental results! When there is a current

or the cathode, according to circumstances

2052)

¶ iii *Active Circles Excited by Solution of Sulphuret of Potassium, &c*

1877 In 1812 Davy gave an experiment to show, that of two different metals, copper and iron that having the strongest attraction for oxygen was positive in oxidizing solutions and that having the strongest attraction for sulphur was positive in sulphuretting solutions[1] In 1827 De la Rive quoted several such inversions of the states of two metals, produced by using different solutions and reasoned from them, that the mere contact of the metals could not be the cause of their respective states but that the chemical action of the liquid produced these states[2]

1878 In a former paper I quoted Sir Humphry Davy's experiment (943), and gave its result as a proof that the contact of the iron and copper could not originate the current produced since when a dilute acid was used in place of the sulphuret, the current was reverse in direction, and yet the contact of the metals remained the same M Marianini[3] adds that copper will produce the same effect with tin lead and even zinc and also that silver will produce the same results as copper In the case of copper he accounts for the effect by referring it to the relation of the iron and the new body formed on the copper, the latter being according to Volta, positive to the former[4] By his own experiment the same substance was negative to the iron across the same solution.[5]

1879 I desire at present to resume the class of cases where a solution of sulphuret of potassium is the liquid in a voltaic circuit for I think they give most powerful proof that the current in the voltaic battery cannot be produced by contact, but is due altogether to chemical action

1880 The solution of sulphuret of potassium (1812) is a most excellent conductor of electricity (1814) When subjected between platinum electrodes to the decomposing power of a small voltaic battery it readily gave pure sulphur at the anode and a little gas which was probably hydrogen, at the cathode When arranged with platinum surfaces so as to form a Ritter's secondary pile the passage of a feeble primary current, for a few seconds only, makes this secondary battery effective in causing a counter current so that, in accordance with the electrolytic conduction (923, 1343), it probably does not conduct without decomposition, or if at all, its point of electrolytic intensity (966, 983) must be very low Its exciting action (speaking on the chemical theory) is either the giving an anion (sulphur) to such metallic and other bodies as it can act upon or in some cases as with the peroxides of lead and manganese, and the protoxide of iron (2046) the abstraction of an anion *from* the body in contact with it, the current produced being in the one or the other direction accordingly Its chemical affinities are such that in many cases its anion goes to that metal of a pair of metals, which is left untouched when the usual exciting electrolytes are employed and so a beautiful inversion of the current in relation to the metals is obtained thus when copper and nickel are used with it, the anion goes to the copper but when the same metals are used with the ordinary electrolytic fluids the anion goes to the nickel Its excellent conducting power renders the currents it can excite very evident and strong and it should be remembered that the strength of the resulting currents, as indicated by the galvanometer, depends *jointly* upon the energy (not the mere quantity) of the exciting action called into play and the conductive ability of the circuit through which the current has to run The value of this exciting electrolyte is increased for the present investigation, by the circumstance of its giving, by its action on the metals resulting compounds some of which are insoluble, whilst others are soluble and, of the insoluble results some are excellent conductors, whilst others have no conducting power at all

1881 The experiments to be described were made generally in the following manner Wires of platinum gold palladium, iron lead, tin, and the other malleable metals about one-twentieth of an inch in diameter and six inches long were prepared Two of these being connected with the ends of the galvanometer wires, were plunged at the same instant into the solution of sulphuret of potassium in a test-glass and kept there without agitation (1919), the effects at the same time being observed The wires were in every case carefully cleansed with fresh fine sand paper and a clean cloth and were sometimes even burnished by a glass rod to give them a smooth surface Precautions were taken to avoid any difference of temperature at the junctions of the different metals with the galvanometer wires

1882 *Tin and platinum* When tin was associated with platinum, gold, or, I may say, any

[1] *Elements of Chemical Philosophy* p. 148

[2] *Annales de Chimie* 1828 XXXVII 231 237, XXXIX, 299

[3] *Memorie della Società Italiana in Modena* 1837, XXI p. 224

[4] *Ibid.*, p. 219

[5] *Ibid.* p. 224.

other metal which is chemically inactive in the

only evident from the present result, but also from a former experiment (1821)

1883 Marianini thinks it is possible that (in the case of copper, at least [1878], and, so I presume, for all similar cases, for surely one law or principle should govern them) the current is due to the contact force of the sulphuret formed But that application is here entirely excluded, for how can a *non-conducting* body form a current, either by contact or in any other way? No such case has ever been shown, nor is it in the nature of things, so that it cannot be the contact of the sulphuret that here causes the current, and if not in the present, why in any case? for nothing happens here that does not happen in any other instance of a current produced by the same exciting electrolyte

1884 On the other hand, how beautiful a proof the result gives in confirmation of the chemical theory! Tin can take sulphur from the electrolyte to form a sulphuret, and whilst it is doing so, and in proportion to the degree in which it is doing so, it produces a current but

1894), and bring about the same result What, then, can be more clear, than that whilst the sulphuret *is being formed a current is produced*, but that when formed its mere contact can do nothing towards such an effect?

1885 *Lead* This metal presents a fine result in the solution of sulphuret of potassium Lead

ment conducted a feeble thermo current ex-

the further chemical action, and that ceasing, the current ceased also

1886 Lead and gold produced the same effect Lead and palladium the same Lead and iron the same, except that the circumstances respecting the tendency of the latter metal under common circumstances to produce a current from the electrolyte to itself, have to be considered and guarded against (1826, 2049) Lead and nickel also the same In all these cases, when *the lead was taken out and washed*, it was found beautifully invested with a thin polished pellicle of sulphuret of lead

1887 With lead, then, we have a *conducting* sulphuret formed, but still there is no sign that its contact can produce a current, any more than in the case of the *non-conducting* sulphuret of tin (1882) There is no new or additional action produced by this *conducting* body, there was no deficiency of action with the former *non-conducting* product, both are alike in their results, being in fact, essentially alike in their relation to that on which the current really depends, namely, an active chemical force A piece of lead put *alone* into the solution of sulphuret of potassium, has its surface converted into sulphuret of lead, the proof thus being obtained, even when the current cannot be formed, that there is a force (chemical) present and active under such circumstances, and such force can produce a current of chemical force when the circuit form is given to the arrangement

bodies produced are conductors, and contact still remains to perform any work or cause any

periment, and that when the action ceases, it is

giving balanced effects of contact in relation to *some* of these bodies, as in this case, to the sulphuret of lead produced, but not with *others*, as the lead itself both the lead and its sulphuret being in the same category as the metals generally (1809, 1870)

1889 The utter improbability of this as a natural effect, and the absence of all experimental proof in support of it, have been already stated (1861, 1871), but one or two additional reasons against it now arise The state of things may perhaps be made clearer by a diagram or two, in which assumed contact forces may be assigned, in the absence of all experimental expression, without injury to the reasoning Let *Fig 4*, Pl XII, represent the electromotive forces of a circle of platinum, iron, and solution of sulphuret of potassium or platinum, nickel, and solution of sulphuret, cases in which the forces are, according to the contact theory, balanced (1860) Then *Fig 5* may represent the circle of platinum, lead, and solution of sulphuret, which does produce a current, and, as I have assumed, with a resulting force of 11 ⟶ This in a few minutes becomes quiescent, i e, the current ceases, and *Fig 6* may represent this new case according to the contact theory Now is it at all likely that by the intervention of sulphuret of lead at the contact *c*, *Fig 5*, and the production of two contacts *d* and *e*, *Fig 6*, such an enormous change of the contact force suffering alteration should be made as from 10 to 21? the intervention of the same sulphuret either at *a* or *b* (1834, 1840) being able to do nothing of the kind, for the sum of the force of the two new contacts is in that case exactly equal to the force of the contact which they replace, as is proved by such interposition making no change in the effects of the circle (1867, 1840) If therefore the intervention of this body between *lead* and platinum at *a*, or between solution of *sulphuret of potassium* and platinum at *b* (*Fig 5*) causes no change, these cases including its contact with both lead and the solution of sulphuret, is it at all probable that its intervention between these two bodies at *c* should make a difference equal to [illegible] the amount of force [illegible] ded [illegible]

a [illegible]

t [illegible] value of its two pl[illegible] contact, is equivalent I think to saying that it partakes of the anomalous character already supposed to belong to certain fluids, namely, of sometimes giving balanced forces in circles of good conductors, and at other times not (1865)

1891 Even the metals themselves must in fact be forced into this constrained condition, for the effect at a point of contact, if there be *any at all*, must be the result of the *joint* and *mutual actions* of the bodies in contact If therefore in the circuit, *Fig 5*, the contact forces are not balanced it must be because of the deficient *joint* action of the lead and solution at *c*.[1] If the metal and fluid were to act in their proper character, and as iron or nickel would do in the place of the lead, then the force there would be ⟵ 21, whereas it is less, or according to the assumed numbers only ⟵ 10 Now as there is no reason why the lead should have *any superiority assigned to it over the solution, since the latter can give a balanced condition amongst* good conductors in its proper situation as well as the former how can this be, unless lead possess that strange character of sometimes giving equipoised contacts, and at other times not (1865)?

1892 If that be true of lead, it must be true of all the metals which, with this sulphuretted electrolyte, give circles producing currents, and this would include bismuth, *copper*, antimony, silver, cadmium, zinc, tin, &c, &c With other electrolytic fluids *iron and nickel would be included, and even gold, platinum, palladium in fact all the bodies that can be made to yield in* any way active voltaic circuits Then is it possible that this can be true, and yet not a single combination of this extensive class of bodies be producible that can give the current without chemical action (1867), considered not as a result, but as a known and pre-existing force?

1893 I will endeavour to avoid further statement of the arguments, but think myself bound to produce (1799) a small proportion of the *enormous body of facts which appear to me to bear evidence all in one direction*

1894 *Bismuth*.—This metal, when associated with platinum, gold, or palladium in solution of the sulphuret of potassium, gives active circles, the bismuth being positive In the course of less than half an hour the current ceases, but the circuit is still an excellent conductor of thermo currents Bismuth with iron or nickel produces the same final result with the reservation before made (1826) Bismuth and lead give an active circle, at first the bismuth is positive

[1] My numbers are assumed and if other numbers were taken the reasoning might be removed to contact *b* or even to contact *a* but the end of the argument would in every case be the same

in a minute or two the current ceases, but the circuit still conducts the thermo current well

1895 Thus whilst sulphuret of bismuth is in the act of formation the current is produced, when the chemical action ceases the current ceases also, though contact continues and the sulphuret be a good conductor In the case of bismuth and lead the chemical action occurs at both sides, but is most energetic at the bismuth, and the current is determined accordingly Even in that instance the cessation of chemical action causes the cessation of the current

1896 In these experiments with *lead* and *bismuth* I have given their associations with platinum, gold, palladium, iron, and nickel because, believing in the first place that the results prove all current to depend on chemical action then, the quiescent state of the resulting or final circles shows that the contacts of these metals in their respective pairs are *without force* (1829) and upon that again follows the passive condition of all those contacts which [illegible]

reasons, that the sulphuret formed is not compact but porous, and does not adhere to the copper, but separates from it in scales Hence results a continued renewal of the chemical action between the metal and electrolyte, and a continuance of the current If after a while the copper plate be taken out and washed, and dried [illegible]

chemical action *continues*, and the coat of sulphuret of copper becomes thicker and thicker

[illegible]

[1] *Memorie della Società Italiana in Modena* 1837, XXI, 224

idea that the mere presence of the sulphuret on it could have caused the former powerful current and positive state of the copper (1878, 1897). A further proof that it is not the mere *presence*, but the *formation*, of the sulphuret which causes the current is, that, if the plate be left long enough for the solution to penetrate the investing crust of sulphuret of copper and come into activity on the metal beneath, then the plate becomes active, and a current is produced

1899 I made some sulphuret of copper, by igniting thick copper wire in a Florence flask or crucible in abundance of vapour of sulphur The body produced is in an excellent form for these experiments, and a good conductor but it is not without action on the sulphuretted solution, from which it can take more sulphur, and the consequence is that it is positive to platinum or iron in such a solution If such sulphuret of copper be left long in the solution, and then be washed and dried it will generally acquire the final state of sulphuration either in parts or altogether and also be inactive, as the sulphuret formed on the copper was before (1898), i e, when its chemical action is exhausted, it ceases to produce a current

1900 *Native gray sulphuret of copper* has the [illegible]

long as the action continues

[illegible]

into a solution of sulphuret of potassium is acted on, and a sulphuret of antimony formed [illegible]

ory of contacts cannot The sulphuret produced in this case is a non-conductor whilst in the

solid state (402), it cannot therefore be that any contact of this sulphuret can produce the current, *in that respect it is like the sulphuret of* tin (1882) But that circumstance does not stop the occurrence of the chemical current, for, as the sulphuret forms a porous instead of a continuous crust, the electrolyte has access to the metal and the action goes on

1903 *Silver* This metal, associated with platinum, iron, or other metals inactive in this electrolyte, is strongly positive, and gives a powerful continuous current Accordingly, if a plate of silver, coated with sulphuret by the simple action of the solution, be examined, it will be found that the crust is brittle and broken, and *separates almost spontaneously from the metal* In this respect, therefore, silver and copper are alike, and the action consequently continues in both cases, but they differ in the sulphuret of silver being a non conductor (434) for these *feeble currents, and, in that respect, this metal* is analogous to antimony (1902)

1904 *Cadmium* Cadmium with platinum, gold, iron, &c, gives a powerful current in the solution of sulphuret, and the cadmium is positive On several occasions this current continued for two or three hours or more, and at such times, the cadmium being taken out, washed and wiped, the sulphuret was found to separate easily in scales on the cloth used

1905 Sometimes the current would soon cease, and then the circle was found not to conduct the thermo current (1813) In these cases, also, on examining the cadmium, the coat of sulphuret was strongly adherent, and this was *more especially the case when prior to the experiment* the cadmium, after having been cleaned, was burnished by a glass rod (1881) Hence it appears that the sulphuret of this metal is a non-conductor, and that its contact could *not have caused the current (1883) in the manner* Marianini supposes All the results it supplies are in perfect harmony with the chemical theory and adverse to contact theory

1906 *Zinc* This metal, with platinum, gold, iron, &c, and the solution of sulphuret, produces a very powerful current, and is positive through the solution to the other metal The current was permanent. Here another beautiful change in the circumstances of the general experiment occurs *Sulphuret of zinc is a non-conductor* of electricity (1821), like the sulphurets of tin, cadmium, and antimony, but *then it is soluble in the solution of sulphuret of* potassium, a property easily ascertainable by putting a drop *of solution of zinc into a portion* of the electrolytic solution, and first stirring them a little, by which abundance of sulphuret *of zinc will be formed*, and then stirring the whole well together, when it will be redissolved The consequence of this solubility is, that the zinc when taken out of the solution *is perfectly* free from investing sulphuret of zinc Hence, therefore, a very sufficient reason, on the chemical theory, why the action should go on. But how can the theory of contact refer the *current to any contact of the metallic sul*phuret, when that sulphuret is, in the first place, a non-conductor, and, in the next, is dissolved and carried off into the solution at the moment of its formation?

1907 Thus all the phenomena *with this ad*mirable electrolyte (1880), whether they be those which are related to it as an active (1879) or as a passive (1825, &c) body, confirm the chemical theory, and oppose that of contact. *With tin and cadmium it gives an impermeable* non-conducting body with lead and bismuth it gives an impermeable conducting body, with antimony and silver it produces a permeable non conducting body, with copper a permeable conducting body, *and with zinc a soluble non* conducting body The chemical action and its resulting current are perfectly consistent with all these variations But try to explain them by the theory of contact, and as far as I can perceive, that can only be done by *twisting the* theory about and making it still more tortuous than before (1861, 1865, 1872, 1874, *1889*), special assumptions being necessary to account for the effects which, under it, become so many special cases

1908 *Solution of protosulphuret of potassium, or bihydrosulphuret of potassa* I used a solution of this kind as the electrolyte in a few cases. The results generally were in accordance with *those already given, but I did not think it nec*essary to pursue them at length The solution was made by passing sulphuretted hydrogen gas for twenty four hours through a strong solution of pure caustic potassa

1909 *Iron and platinum* with this solution formed a circle in which the iron was first negative, then gradually became neutral, *and finally* acquired a positive state The solution first acted as the yellow sulphuret in reducing the *investing oxide* (2049), and then apparently directly on the iron, dissolving the sulphuret formed Nickel was positive *to platinum from* the first, and continued so though producing only a weak current When weak *chemical ac*tion was substituted *for metallic contact at a*

(Pl XII, *Fig 2*) (1831), a powerful current passed Copper was highly positive to iron and nickel as also to platinum, gold, and the other metals which were unacted upon by the solution Silver was positive to iron, nickel, and even lead, as well as to platinum, gold, &c Lead is positive to platinum, then the current falls, but does not cease Bismuth is also positive at first, but after a while the current almost entirely ceases, as with the yellow sulphuret of potassium (1894)

1910 N

ga tus, were inactive with these metals in this solution, as before they had been with the solution of yellow or bisulphuret of potassium This solution, as might be expected from its composition, has more of alkaline characters in it than the yellow sulphuret of potassium

1911 Before concluding this account of results with the sulphuretted solutions, as exciting electrolytes, I will mention the varying and beautiful phenomena which occur when copper and silver, or two pieces of copper, or two pieces of silver, form a circle with the yellow solution If the metals be copper and silver, the copper is at first positive and the silver remains untarnished, in a short time this action ceases, and the silver becomes positive, at the same instant it begins to combine with sulphur and becomes covered with sulphuret of silver, in the course of a few moments the copper again becomes positive, and thus the action will change from side to side several times, and the current with it, according as the circumstances become in turn more favourable at one side or the other

1912 But how can it be thought that the current first produced is due in any way to the *contact* of the sulphuret of copper formed, since its presence there becomes at last the reason why that first current diminishes, and enables the silver, which is originally the weaker in exciting force, and has no sulphuret as yet formed on it, to assume for a time the predominance, and produce a current which can overcome that excited at the copper (1911)? What can account for these changes, but chemical action which, as it appears to me, accounts, as far as we have yet gone, with the utmost simplicity, for *all* the effects produced, however varied the mode of action and their circumstances may be?

Royal Institution, December 12, 1839

SEVENTEENTH SERIES

§ 24. *On the Source of Power in the Voltaic Pile* (*continued*) ¶ iv. *The Exciting Chemical Force Affected by Temperature* ¶ v. *The Ex-*

Received January 30, Read March 19, 1840

¶ iv. *The Exciting Chemical Force Affected by Temperature*

1913 On the view that chemical force is the origin of the electric current in the voltaic circuit, it is important that we have the power of

enough to produce currents without any metallic contact at all

1914 De la Rive has shown that the increased action of a pair of metals, when put into hot fluid instead of cold, is in a great measure due to the exaltation of the chemical affinity on that metal which was acted upon [1] My object

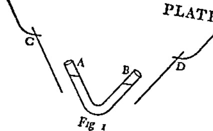


Fig 1

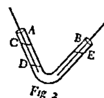


Fig 2

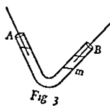


Fig 3

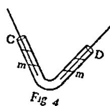


Fig 4

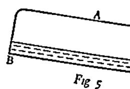


Fig 5

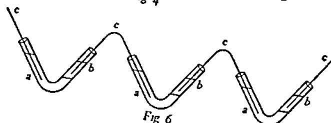


Fig 6

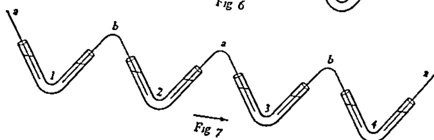


Fig 7

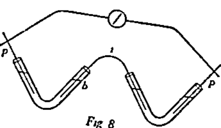
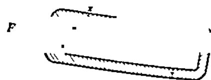
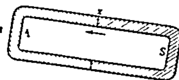


Fig 8







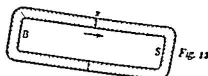


Fig. 12

tion of heat If such difference produced a current with circles which either did not generate a thermo current themselves, or could not conduct that of an antimony and bismuth element, it seemed probable that the effect would prove to be a result of pure chemical force, contact doing nothing

1915 The apparatus used was a glass tube (Pl XIII, *Fig 1*) about five inches long and 0 4 of an inch internal diameter, open at both ends, bent, and supported on a retort-stand In this the liquid was placed, and the portion in the upper part of one limb could then easily be heated and retained so, whilst that in the other limb was cold In the experiments I will [illegible]

a circuit by means of the galvanometer, and, often also, a Seebeck's thermo-element of antimony and bismuth, both these, of course, caused no disturbing effect so long as the temperature of their various junctions was alike The wires were carefully prepared (1881), and when two of the same metal were used, they consisted of the successive portions of the same piece of wire

1916 The precautions which are necessary for the elimination of a correct result are rather numerous, but simple in their nature

1917. *Effect of first immersion.* It is hardly possible to have the two wires of the same metal, even platinum, so exactly alike that they shall not produce a current in consequence of their difference, hence it is necessary to alternate the wires and repeat the experiment several times, until an undoubted result independent of such disturbing influences is obtained

1918 [illegible]

[illegible]

face (1003, 1036, 1037), and the consequent final superiority of the colder side at which the action was thus necessarily more powerful (1953, &c , 1966, 2015, 2031, &c) Marianini has described many cases of the effects of investing solutions, showing that if two pieces of the same metal (iron, tin, lead, zinc, &c) be used, [illegible]

then to observe the *first effect* produced, accounting that as the true indication, but repeating the experiment until the result was certain

1919 *Effect of motion* This investing fluid (1918) made it necessary to guard against the effect of successive rest and motion of the metal [illegible]

force rose up again to 80° The precaution adopted to avoid the interference of these [illegible]

to boiling, the moment the fluid was agitated on the tin side by the boiling on the cadmium side, there was more effect by far produced by the motion than the heat for the heat at the cadmium alone did little or nothing, but the jumping of the acid over the tin made a difference in the current of 20° or 30°.

1921 *Effect of air* Two platinum wires were put into cold strong solution of sulphuret of potassium (1812), (Pl XIII, *Fig 1*) and the galvanometer was soon at 0° On heating and boiling the fluid on the side A (1915) the platinum in it became negative cooling that side, by pouring a little water over it from a jug, and heating the side B, the platinum there in turn became negative and, though the action was irregular, the same general result occurred however the temperatures of the parts were altered This was not due to the chemical effect of the electrolyte on the heated platinum Nor do I believe it was a true thermo current (1933), but if it were the latter, then the heated platinum was *negative* through the electrolyte to the cold platinum I believe it was altogether the increased effect of the air upon the electrolyte at the heated side, and it is evident that the application of the heat, by causing currents in the fluid and also in the air, facilitates their mutual action at that place It has been already shown that lifting up a platinum wire in this solution, so as to expose it for a moment to the air (1827), renders it negative when re-immersed, an effect which is in perfect accordance with the assumed action of the heated air and fluid in the present case The interference of this effect is obviated by raising the temperature of the electrolyte quietly before the wires are immersed (1918), and observing only the first effect

1922 *Effect of heat* In certain cases where two different metals are used, there is a very remarkable effect produced on heating the negative metal This will require too much detail to be described fully here but I will briefly point it out and illustrate it by an example or two

1923 When two platinum wires were compared in hot and cold dilute sulphuric acid (1935), they gave scarcely a sensible trace of any electric current If any real effect of heat occurred, it was that the hot metal was the least degree positive When silver and silver were compared, hot and cold, there was also no sensible effect But when platinum and silver were compared in the same acid, different effects occurred Both being cold, the silver in the A side (Pl XIII, *Fig 1*) (1915) was positive about 4°, by the galvanometer, moving the platina on the other side B did not alter this effect, but on heating the acid and platinum there, the current became very powerful, deflecting the needle 30°, and the silver was positive Whilst the heat continued, the effect continued but on cooling the acid and platinum it went down to the first degree No such effect took place at the silver, for on heating that side instead of becoming negative, it became more positive, but only to the degree of deflecting the needle 16° Then, *motion* of the platinum (1919) facilitated the passing of the current and the deflection increased, but *heating* the platinum side did far more

1924 *Silver and copper* in dilute sulphuric acid produced very little effect, the copper was positive about 1° by the galvanometer, moving the copper or the silver did nothing heating the copper side caused no change, but on heating the silver side it became negative 20° On cooling the silver side this effect went down, and then, either moving the silver or copper, or heating the copper side, caused very little change but heating the silver side made it negative as before

1925 All this resolves itself into an effect of the following kind, that where two metals are in the relation of positive and negative to each other in such an electrolyte as dilute acids (and perhaps others), heating the negative metal at its contact with the electrolyte enables the current, which tends to form, to pass with such facility, as to give a result sometimes *tenfold* more powerful than would occur without it It is not displacement of the investing fluid for motion will in these cases do nothing it is not chemical action, for the effect occurs at that electrode where the chemical action is not active it is not a thermo-electric phenomenon of the ordinary kind, because it depends upon a voltaic relation, i e, the metal showing the effect must be negative to the other metal in the electrolyte so silver heated does nothing with silver cold, though it shows a great effect with copper either hot or cold (1924), and platinum hot is as nothing to platinum cold, but much to silver either hot or cold

1926 Whatever may be the intimate action of heat in these cases, there is no doubt that it is dependent on the current which tends to pass round the circuit It is essential to remember that the increased effect on the galvanometer is not due to any increase in the electromotive force, but solely to the removal of obstruction to the current by an increase probably

the positive electrode when a voltaic battery was used (1639), but I have no doubt the present phenomena will prove to be virtually the same as those which that philosopher has described

1927. The effect interferes frequently in the ensuing experiments when *two* metals, hot and cold, are compared with each other, and the more so as the negative metal approximates in inactivity of character to platinum or rhodium

fluid, as in the figure, there were irregular movements of the galvanometer, small in degree, leaving the B wire positive Moving the wires about, but retaining them as in the figure,

fluid in tube A

[1] *Bibliothèque Universelle* 1837, VII,

1929 *Cleaning the wires* That this should be carefully done has been already mentioned (1881), *but it is especially* necessary to attend to the very extremities of the wires, for if these circular spaces, which occur in the most effective part of the circle, be left covered with the body produced on them in a preceding trial, an experimental result will often be very much deranged, or even entirely falsified

1930 Thus the best mode of experimenting (1915) is to heat the liquid in the limb A or B (Pl XIII, *Fig 2*), first and, having the wires well cleaned and connected, to plunge both in at once, and, retaining the *end* of the heated wire in the hot part of the fluid, to keep both wires in motion, and observe, especially, the

factory conclusion

1931 It next becomes necessary to ascertain whether any true thermo current can be produced by electrolytes and metals, which can interfere with any electro-chemical effects dependent upon the action of heat For this purpose different combinations of electrolytes and metals not acted on chemically by them, were tried, with the following results

that could deflect the galvanometer needle about 5°, when the temperatures at the two junctures were 60° and 240° Gold and the same solution

and there was a constant current and deflection of 50° or more, *but there was also chemical action (1948)*

degree negative Gold in the same acid gave a scarcely sensible result, the hot metal was negative Palladium was as gold

1935 With dilute sulphuric acid, consisting of one by weight of oil of vitriol and eighty of water, neither platinum nor gold produced any sensible current to my galvanometer by the mere action of heat

1936 *Muriatic acid* and platinum being conjoined, and heated as before, the hot platinum was very slightly negative in strong acid in dilute acid there was no sensible current

1937 *Strong nitric acid* at first seemed to give decided results Platinum and pure strong nitric acid being heated at one of the junctions, the hot platinum became constantly negative across the electrolyte to the cold metal, the deflection being about 2° When a yellow acid was used, the deflection was greater, and when a very orange-coloured acid was employed, the galvanometer needle stood at 70°, the hot platinum being still negative This effect, however, *is not a pure thermo current, but a peculiar result due to the presence of nitrous acid* (1848) It disappears almost entirely when a dilute acid is used (1934), *and what effect does remain in*dicates that the hot metal is negative to the cold

1938 Thus the *potash solution* seems to be *the fluid giving the most probable indications* of a thermo current Yet there the deflection is only 5°, though the fluid, being very strong, is *a good conductor (1819) When the fluid was* diluted, and of specific gravity 1070, like that before used (1932), the effect was only 1°, and *cannot therefore be confounded with the re*sults I have to quote

1939 The dilute *sulphuric* (1935) and *nitric acids* used (1931) *gave only doubtful indica*tions in some cases of a thermo current On trial it was found that the thermo current of an *antimony-bismuth pair could not pass these* solutions, as arranged in these and other experiments (1949, 1950) that, therefore, if the *little current obtained in the experiments be of* a thermo-electric nature, this combination of platinum and acid is far more powerful than *the antimony bismuth pair of Seebeck* and yet that (with the interposed acid) it is scarcely sensible by this delicate galvanometer Further, when there is a current, the hot metal is generally negative to the cold, and it is therefore impossible to confound these results with those *to be described where the current has a* contrary direction

1940 In strong nitric acid, again, the hot metal *is negative*

1941 *If, after I show that heat applied to* metals in acids or electrolytes which *can act on them* produces considerable currents, it be then said that though the metals which are inactive in the acids produce no thermo currents those which, like copper, silver, &c , act chemically, may, then, I say, that such would be a mere supposition, and a supposition at variance with what we know of thermo-electricity, for amongst the solid conductors, metallic or non metallic (1867), there are none, I believe, which are able to produce thermo currents with some of the metals, and not with others Further, these metals, copper, *silver, &c , do not always* show effects which can be mistaken or pass for thermo-electric, for silver in hot dilute nitric *acid is scarcely different from silver in the same* acid cold (1950) and in other cases, again, the hot metals become negative instead of positive (1953)

Cases of One Metal and One Electrolyte, One Junction Being Heated

1942 The cases I have to adduce are far too numerous to be given in detail I will therefore describe one or two, and sum up the rest as briefly as possible

1943 *Iron in diluted sulphuret of potassium The hot iron is well positive to the cold metal.* The negative and cold wire continues quite clean but from the hot iron a dark sulphuret *separates which becoming diffused through the* solution discolours it When the cold iron is taken out, washed and wiped, it leaves the *cloth clean but that which has been heated* leaves a black sulphuret upon the cloth when similarly treated

1944 *Copper and the sulphuretted solution.* The hot copper is well positive to the cold on the first immersion, but the effect quickly *falls, from the general causes already referred to* (1918)

1945 *Tin and solution of potassa The hot tin is strongly and constantly positive to the* cold

1946 *Iron and dilute sulphuric acid* (1935) The hot *iron* was constantly positive to the cold, 60° or more *Iron and diluted nitric acid gave* even a still more striking result

I must now enumerate merely, not that the cases to be mentioned are less decided than those already given, but to economize time.

1947 *Dilute solution of yellow sulphuret of potassium,* consisting of one volume of the strong solution (1812), and eighteen *volumes of water* Iron, silver, and copper, with this solution,

gave good results The hot metal was positive to the cold

1948 *Dilute solution of caustic potassa* (1932) Iron copper, tin zinc, and cadmium gave striking results in this electrolyte The hot metal was always positive to the cold Lead produced the same effect, but there was a momentary jerk at the galvanometer at the instant of immersion, as if the hot lead was negative at that moment In the case of iron it was necessary to continue the application of heat, and then the formation of oxide at it could easily be observed, the alkali gradually became turbid for the protoxide first formed was dissolved and becoming peroxide by degrees, was deposited, and rendered the liquid dull and yellow

1949 *Dilute sulphuric acid* (1935) Iron tin, lead and zinc, in this electrolyte showed the power of heat to produce a current by exalting the chemical affinity, for the hot side was in each case positive

1950 [illegible]

is iron with silver, copper and zinc, the hot side is at the first moment positive to the cold, but only in the smallest degree

1951 *Strong nitric acid* Hot iron is positive to cold Both in the hot and cold acid the iron is in its peculiar state (1844 2001)

1952 *Dilute muriatic acid 1 volume strong muriatic acid and 29 volumes water* This acid was as remarkable for the number of cases it [illegible]

permanency of the electric current produced

1953 [illegible]

the solution of the *sulphuret of potassium* and zinc, on the first immersion of the wires into [illegible]

same solution gave also the first pause and then a current, the hot metal being negative, but the effect was very small. Lead hot, was negative producing also only a feeble current Tin gave the same result, but the current was scarcely sensible

1954 *In dilute sulphuric acid* Copper and zinc, after having produced a first positive effect at the hot metal, had that reversed, and a feeble current was produced the hot metal being negative Cadmium gave the same phenomena, but stronger (1918)

1955 *In dilute nitric acid* Lead produced no [illegible]

1956 I cannot but view in these results of [illegible]

see how the theory of contact can take cognizance of them except by adding new assumptions to those already composing it (1874) How, for instance can it explain the powerful effects of iron in sulphuret of potassium or in [illegible]

these cases It seems to me that no other cause than chemical force (a very sufficient one) remains or is needed to account for them

1957 If it be said that, on the theory of chemical excitement, the experiments prove [illegible]

used, then, I say that that does not follow [illegible] force and other circumstances of chemical affinity vary almost infinitely with the bodies ex- [illegible]

duced, and it is well known that, in almost every voltaic circuit, the chemical force has to be considered as divided into that which is local and that which is current (1120) Now heat frequently assists the local action much, *and, sometimes, without appearing to be accompanied by any great increase in the intensity* of chemical affinity whilst at other times we are sure, from the chemical phenomena, that it does affect the intensity of the force The electric current, however, is not de[illegible] the amount of [illegible] the in[illegible] cases [illegible], in which that metal [illegible]ing the least amount of action is nevertheless the positive metal in a voltaic circuit, *as with copper in weak nitric acid* associated with other copper in strong acid (1975), or iron or silver in the same weak acid against copper in the strong acid (1996) Many of those instances where the hot side ultimately becomes negative, as of zinc in dilute solution of sulphuret of potassium (1953), or cadmium and lead in dilute nitric acid (1955), are of this *nature and yet the conditions and result are in* perfect agreement with the chemical theory of voltaic excitement (1918)

1958 The *distinction between currents* founded upon that difference of intensity which is due to the difference in force of the chemical action which is their exciting cause, is *I think*, a necessary consequence of [illegible] ory [illegible] such a principle,[1] [illegible] that the intensity of currents is exactly proportional to the degree of affinity which reigns between the particles, the com*bination or separation of which produces the* currents

1959 I look upon the question of the origin of the power in the voltaic battery as abundantly decided by the experimental results not connected with the action of heat (1824, &c 1878, &c) I further view the results with heat as adding very strong confirmatory evidence to the chemical theory and the numerous questions which arise as to the varied results produced, only tend to show how important the *voltaic circuit is as a means of* investigation into the nature and principles of chemical affinity (1967) This truth has already been most *strikingly illustrated by the researches of De la* Rive made by means of the galvanometer, and the investigations of my friend Professor Daniell into the real nature of acid and other compound electrolytes[2]

Cases of Two Metals and One Electrolyte One Junction Being Heated

1960 Since heat produced such striking results with single metals, I thought it probable that it might be able to affect the mutual relation of the metals in some cases, and even invert their order on making circuits with two metals and electrolytes, I found the following cases

1961 *In the solution of sulphuret of potassium*, hot tin is well positive to cold silver cold tin is very slightly positive to hot silver, and *the silver then rapidly tarnishes*

1962 In the solution of *potassa*, cold tin is fairly positive to hot lead, but hot tin is much more positive to cold lead Also cold cadmium is positive to hot lead, but hot cadmium is far *more* positive to cold lead In these cases, therefore, there are great differences produced by heat, but the metals still keep their order

1963 *In dilute sulphuric acid*, hot iron is *well positive* to cold tin, but hot tin is *still more positive* to cold iron Hot iron is a little positive *to cold lead, and hot lead is very positive to* cold iron These are cases of the actual inversion of order, and tin and lead may have their states reversed exactly in the same manner

1964 *In dilute nitric acid*, tin and iron, and iron and lead may have their states reversed, whichever is the hot metal being rendered positive to the other If, when the iron is to be plunged into the heated side (1930) the acid is only moderately warm, it seems at first as if the tin would almost overpower the iron, *so beautifully can the forces be either balanced or* rendered predominant on either side at pleasure. Lead is positive to tin in both cases but far more so when hot than when cold

1965 These effects show beautifully that, in many cases, when two different metals are taken, either can be made positive to the other at pleasure, by acting on their chemical affinities, though the contacts of the metals with each other (supposed to be an electromotive cause) remain *entirely unchanged* They show the effect of heat in reversing or strengthening the natural differences of the metals, according as its action is made to oppose or combine with *their natural chemical forces*, and thus add further confirmation to the mass of evidence already adduced

[1] *Philosophical Transactions* 1831 p 428.
[2] *Annales de Chimie*, 1836, LXI, p 44 &c.
[3] *Philosophical Transactions*, 1839, p. 97.

1966 There are here, as in the cases of one metal, some instances where the heat renders the metal more negative than it would be if cold They occur, principally, in the solution of sulphuret of potassium Thus, with zinc and cadmium, or zinc and tin, the coldest metal is positive With lead and tin, the hot tin is a little positive, cold tin very positive With lead and zinc, hot zinc is a little positive, cold zinc much more so With silver and lead, the hot silver is a little positive to the lead, the cold silver is more, and well positive In these cases the current is preceded by a moment of qui-

metal, and the latter afterwards shows its advantage

1967 Before concluding these observations on the effects of heat, and in reference to the probable utility of the voltaic circuit in investigations of the intimate nature of chemical

positive to the tin So that a difference of temperature not limited to one contact, for the two

taneous immersion, observation of the first effects, &c, were attended to

¶ v *The Exciting Chemical Force Affected by Dilution*

1969 Another mode of affecting the chemical affinity of these elements of voltaic circuits, the metals and acids, and also applicable to the cases of such circuits, is to vary the proportion of water present Such variation is known, by the simplest chemical experiments, to affect very importantly the resulting actic

upon the chemical theory, it was natural to expect that it would also produce some corresponding change in the voltaic pile The effects observed by Avogadro and Oersted in 1823 are in accordance with such an expectation, for

current took place [1] In 1828 De la Rive carried these and similar cases much further, especially in voltaic combinations of copper and iron with lead [2] In 1827 Becquerel[3] experimented with

I think of very great importance

1970 The argument derivable from effects of this kind appeared to me so strong that I worked out the facts to some extent, and think

tive force of *mere contact* did not seem evident to me, without *assuming*, as before (1874), exactly those influences at the points of contact in the various cases, which the prior results,

been described long since by Becquerel,[5] but whose influence in the present researches re-

the end of the wire D upwards above *m*, or de-

[1] *Annales de Chimie* 1823 XXII p 361
[2] *Ibid* 1828 XXXVII p 234
[3] *Ibid* 1827 XXXV p 120
[4] *Ibid* 1828 XXXVII, p 240 241
[5] *Traité de l Electricité* II p 81.

1973 When the tube was arranged, as in *Fig 3*, with water or dilute acid on one side only, and the wires were immersed not more than one third of an inch, the effects were greatly diminished, and more especially, if, by a little motion with a platinum wire, the acids had been mixed at *m*, so that the transition from weak to strong was gradual instead of sudden In such cases even when the wires were moved, horizontally, in the acid, the effect was so small as to be scarcely sensible, and not likely to be confounded with the chemical effects to be described hereafter Still more surely to avoid such interference, an acid moderately diluted was used instead of water The precaution was taken of emptying, washing, and re-arranging the tubes with fresh acid after each experiment, lest any of the metal dissolved in one experiment should interfere with the results of the next

1974 I occasionally used the tube with dilute acid on one side only, (Pl XIII *Fig 3*,) and sometimes that with dilute acid on both sides, *Fig 4* I will call the first No 1 and the second No 2

1975 In illustration of the general results I will describe a particular case Employing tube No 1 with strong and dilute nitric acid,[1] and two copper wires, the wire in the dilute acid was powerfully positive to the one in the strong acid at the first moment, and continued so By using tube No 2 the galvanometer needle could be held stiffly in either direction simply by simultaneously raising one wire and depressing the other, so that the first should be in weak and the second in strong acid the former was always the positive piece of metal

1976 On repeating the experiments with the substitution of platinum, gold, or even palladium for the copper, scarcely a sensible effect was produced (1973)

1977 *Strong and dilute nitric acid*[1] The following single metals being compared with themselves in these acids, gave most powerful results of the kind just described with copper (1975), silver, iron, lead, tin, cadmium, zinc The metal in the weaker acid was positive to that in the stronger Silver is very changeable, and after some time the current is often suddenly reversed, the metal in the strong acid becoming positive this again will change back, the metal in the weaker acid returning to its positive state With tin, cadmium, and zinc, violent action in the acid quickly supervenes and mixes all up together. Iron and lead show the alternations of state in the tube No 2 as beautifully as copper (1975)

[1] The dilute acid consisted of three volumes of strong nitric acid and two volumes of water

1978 *Strong and dilute sulphuric acid* I prepared an acid of 49 by weight, strong oil of vitriol, and 9 of water, giving a sulphuric acid with two proportions of water, and arranged the tube No 1 (1974) with this and the strongest acid But as this degree of dilution produced very little effect with the iron, as compared with what a much greater dilution effected I adopted the plan of putting strong acid into the tube, and then adding a little water at the top at one of the sides, with the precaution of stirring and cooling it previous to the experiment (1973)

1979 With iron, the part of the metal in the weaker acid was powerfully positive to that in the stronger acid With copper, the same result, as to direction of the current, was produced but the amount of the effect was small With silver, cadmium, and zinc, the difference was either very small or unsteady, or nothing so that, in comparison with the former cases, the electromotive action of the strong and weak acid appeared balanced With lead and tin, the part of the metal in the *strong* acid was positive to that in the weak acid so that they present an effect the reverse of that produced by iron or copper

1980 *Strong and dilute muriatic acid* I used the strongest pure muriatic acid in tube No 1, and added water on the top of one side for the dilute extremity (1973), stirring it a little as before With silver, copper, lead, tin, cadmium, and zinc, the metal in the *strongest* acid was positive, and the current in most cases powerful With iron, the end in the strongest acid was first positive but shortly after the weak acid side became positive and continued so. With palladium, gold, and platinum, nearly insensible effects were the results

1981 *Strong and dilute solution of caustic potassa* With iron, copper, lead, tin, cadmium, and zinc, the metal in the strong solution was positive in the case of iron slightly, in the case of copper more powerfully, deflecting the needle 30° or 38°, and in the cases of the other metals very strongly Silver, palladium, gold, and platinum, gave the merest indications (1973)

Thus potash and muriatic acid are, in several respects, contrasted with nitric and sulphuric acids As respects muriatic acid however, and perhaps even the potash it may be admitted that, even in their strongest states,

they are not fairly comparable to the very strong nitric and sulphuric acids, but rather to those acids when somewhat diluted (1985)

1982 I know it may be said in reference to the numerous changes with strong and dilute acids, that the results are the consequence of

duced at the metallic surfaces which *differing* causes difference of effect, but this is to put

given are consistent with the extreme variety which chemical action under different circum stances possesses but as it still appears to me, are utterly incompatible with, what should be, the simplicity of mere contact action further they admit of even greater variation which renders the reasons for the one view and against

1978) then the following result is an answer to such an assumption Iron in *dilute nitric acid* consisting of one volume of strong acid and twenty of water, is positive to iron in strong acid or in a mixture of one volume of

1985 Or if, modifying the statement upon these results it should be said that diluting

then, how is it that with muriatic acid and potassa the effect of dilution is the reverse of that which has been quoted in the cases with nitric acid and iron or silver (1977, 1984)? Or if to avoid *difficulty* it be assumed that each electrolyte must be considered apart, the nitric acid by itself and the muriatic acid by itself, for that one may differ from another in the *direction* of the change induced by dilution, then how can the following results with a single acid be accounted for?

1986 I prepared four nitric acids

A was very strong pure nitric acid
B was one volume of A and one volume of water,
C was one volume of A and three volumes of water,
D was one volume of A and twenty volumes of water

1988 I prepared also three sulphuric acids

E was strong oil of vitriol
F one volume of E and two volumes of water
G one volume of E and twenty volumes of water

Lead in F was well *negative* to lead either in E

used platinum wires ultimately in all these cases with the same acids to check the inter ference of the combination of acid and water (1973), but the results were then almost noth ing and showed that the phenomena could not be so accounted for

acid strong and diluted, some metals are posi tive in the strong acid and others in the weak.

(1988) was positive to tin in the moderate or the weak acids F and G, and tin in the moderate acid F was positive to the same metal in G Iron on the contrary, being in the strong acid E was negative to the weaker acids F and G, and iron in the medium acid F was negative to the same metal in G

1990 For the purpose of understanding more distinctly what the contact theory has to do here, I will illustrate the case by a diagram Let Pl XIII *Fig 5* represent a circle of [illegible] and sulphuric acid If [illegible] conne[illegible] [illegible] be weak [illegible] such current but let it be s[illegible] acid at B, and diluted at C, and an electric current will run round A C B If the metal A be silver, it is equally indifferent with the strong and also with the weak acid as iron has been found to be as to the production of a current but, besides that it is indifferent with the strong acid at B and the weak acid at C Now if the dilution of the electrolyte at one part, as C, had so far increased the contact electromotive force there, when iron or copper was present, *as to produce the current found by experiment, surely it ought (consistently with any reasonable limitations of the assumptions in* the contact theory) to have *produced* the same effect with silver but there was none Making the metal A lead or tin the difficulty becomes far greater for though with the strong or the weak acid alone any effect of a determinate current is nothing yet one occurs upon dilution at C, but now dilution must be supposed to *weaken* instead of *strengthen* the contact force, for the current is in the reverse direction

1991 Neither can these successive changes be referred to a gradual progression in the effect of dilution dependent upon the *order of the metals* For supposing dilution more favourable to the electromotive force of the contact of an acid and a metal in *proportion* as the metals were in a certain order, as for instance that of their efficacy in the voltaic battery, though such an assumption might seem to account for the gradual diminution of effect from iron to copper, and from copper to silver, one would not expect the reverse effects, or those on the other side of zero, to appear by a return back to such metals as lead and tin (1979, 1989), but rather look for them in platinum or gold, which, however, produce no results of the kind (1976, 1988) To increase still further this complexity, it appears, from what has been before stated, that on changing the *acids* the order must again be changed (1981); nay, more, that with the same acid, and merely by changing the proportion of dilution, such alteration of the order must take place (1986, 1988)

1992 Thus it appears, as before remarked (1982), that to apply the theory of contact electromotive force to the facts, that theory must twist and bend about with every variation of chemical action, and after all, with every variety of contact, active and inactive, in no case presents phenomena independent of the active exertion of chemical force

1993 As the influence of dilution and concentration was so strong in affecting the relation of different parts of the same metal to an acid, making one part either positive or negative to another, I thought it probable that by mere variation in the strength of the interposed electrolyte, the order of metals when in acids or other solutions of uniform strength, might be changed I therefore proceeded to experiment on that point, by combining together two metals, tin and lead, through the galvanometer (1915), arranging the electrolytic solution in tube No 1, strong on one side and weak on the other *immersing the wires simultaneously, tin into the strong, and lead into the weak solution, and after observing the effect, re-cleaning the wires, re-arranging the fluid, and re immersing the wires, the tin into the weak, and the lead into the strong* portion De la Rive has already stated[1] that inversions take place when dilute and strong sulphuric acid is used, these I could not obtain when care was taken to avoid the effect of the investing fluid (1918) the general statement is correct, however, when applied to another acid, and I think the evidence very important to the consideration of the great question of contact or chemical action

1994 *Two metals in strong and weak solution of potash* Zinc was positive to tin, cadmium, or lead, whether in the weak or strong solution Tin was positive to cadmium, either in weak or strong alkali Cadmium was positive to lead both ways, but most when in the strong alkali Thus, though there were *differences in degree* dependent on the strength of the solution, there was *no inversion of the order of the metals*

1995 *Two metals in strong and weak sulphuric acid* Cadmium was positive to iron and tin both ways tin was also positive to iron, copper, and silver, and iron was positive to copper and silver, whichever side the respective metals were in Thus none of the metals tried

[1] *Annales de Chimie*, 1828 XXXVII p. 240.

ould be made to pass the others, and so take a ifferent order from that which they have in cid uniform in strength Still there were great ariations in degree, thus iron in strong acid was nly a little positive to silver in weak acid, but on in weak acid was very positive to silver in rong acid Generally the metal, usually called ositive, was most positive in the weak acid, ut that was not the case with lead, tin, and zinc

1996 *Two metals in strong and weak nitric cid* Here the degree of change produced by ifference in the strength of the acid was so reat as to cause not merely difference in degree, but inversions of the order of the metals, f the most striking nature Thus iron and

nake either positive at pleasure (1975) Cop-

ead, copper, and, though slightly, even to tin, n strong acid Tin in weak acid was positive to opper, lead, iron, zinc, and silver, and either neutral or a little positive to cadmium in strong acid Cadmium in weak acid is very positive,

1997 Thus wonderful changes occur amongst

metals only may therefore be varied about one hundred different ways in the same acid, merely by the effect of dilution

1998 So also zinc, tin, cadmium and lead, and likewise zinc, tin, iron, and lead, being groups each of four metals, any one of these metals may be made either positive or negative to any other metal of the same group, by dilution of this acid

1999 But the case of variation by dilution may, as regards the opposed theories be made even still stronger than any yet stated, for the *same metals* in the *same acid* of the *same strength at the two sides* may be made to change their order, as the chemical action of the acid on each particular metal is affected, by dilution, in a smaller or greater degree

2000 A voltaic association of iron and silver

the same results were obtained

2033), and as the action on the iron in its *ordinary* state may be said to be, to render it positive to the silver or copper, both in the strong or weak acid, we will not endeavour to force the fact, but look to other metals

2002 *Silver and nickel* being associated in weak nitric acid, the nickel was positive, being

positive to the copper Again, *zinc and cadmium*

unexceptionable cases (1999)

2004 Thus the nitric acid furnishes a most wonderful variety of effects when used as the electrolytic conductor in voltaic circles, and its difference from sulphuric acid (1995) or from potassa (1994) in the phenomena consequent upon dilution, tend, in conjunction with many preceding facts and arguments, to show that the electromotive force in a circle is not the consequence of any power in bodies

belonging to them in classes rather than as individuals, and having that simplicity of character which contact force has been assumed to have, but one that has all the variations which chemical force is *known* to exhibit

2005 The changes occurring where any one of four or five metals, differing from each other as far as silver and tin can be made positive or negative to the others (1997 1998), appears to me to shut out the probability that the contact of these metals with each other can produce *the smallest portion of the effect in these* voltaic arrangements and then, if not there *neither can they be effective in any other arrangements* so that what has been deduced in that respect *from former experiments* (1829 1833) is confirmed by the present

2006 Or if the scene be shifted, and it be said that it is the *contact* of the acids or solutions which by dilution at one side, produce these varied changes (1874, 1982, 1991, 2014, 2060), then how *utterly unlike* such contact must be to that of the numerous class of conducting solid bodies (1809, 1867)! And where, to give the assumption any show of support, is the case of such contact (apart from chemical *action*) *producing such currents?*

2007 That it cannot be an alteration of contact force by mere dilution at one side (2006) is also shown by making such a change but using metals that are chemically inactive in the electrolyte employed Thus when nitric or sulphuric acids were diluted at one side and then the strong and the weak parts connected by platinum or gold (1976), there was no sensible current, or only one so small as to be unimportant

2008. *A still stronger proof is afforded by the* following result. I arranged the tube (Pl XIII, *Fig 8*) (1972), with strong solution of yellow sulphuret of potassium (1812) from A to *m*, and a solution consisting of one volume of the strong solution, with six of water from *m* to B The extremities were then connected by platinum and iron in various ways, and when the first effect of immersion was guarded against, including the first brief negative state of the iron (2049), the effects were as follows Platinum *being in A and in B, that in A, or the* strong solution, was very slightly positive, causing a permanent deflection of 2° Iron being in A and in B, the same result was obtained Iron being in A and platinum in B, the iron was positive about 2° to the platinum. Platinum being in A and iron in B, the platinum was now positive to the iron by about 2° So that not *only the contact of the iron and platinum passes* for nothing but the contact of strong and weak solution of this electrolyte with either iron or platinum, is ineffectual in producing a current The current which is constant is very feeble and evidently related to the mutual position of the strong and weak solutions, and is probably due to their gradual mixture

2009 The results obtained by dilution of an electrolyte capable of acting on the metals employed to form with it a voltaic circuit, may in *some cases depend on making the acid a better* electrolyte It would appear, and would be ex*pected from the chemical theory, that whatever circumstance tends to make the fluid a more powerful chemical agent and a better* electrolyte (the latter being a relation purely chemical and not one of contact) favours the production of a determinate current Whatever the cause of the effect of dilution may be, the results still tend to show how valuable the voltaic circle will become as an investigator of the nature of chemical affinity (1959)

¶ vi *Differences in the Order of the Metallic Elements of Voltaic Circles*

2010 Another class of experimental arguments, bearing upon the great question of the origin of force in the voltaic battery, is supplied by a consideration of the different order in which the metals appear as electromotors when associated with different exciting electrolytes The metals are usually arranged in a certain order and it has been the habit to say that a metal in the list so arranged is negative *to any one above it, and positive to any one be*neath it, as if (and indeed upon the conviction *that) they possessed a certain direct power* one with another But in 1812 Davy showed inver*sions of this order in the case of iron and cop*per[1] (943), and in 1828 De la Rive showed many inversions in different cases[2] (1877) gave a strong contrast in the order of certain metals in strong and dilute nitric acid;[3] and in objecting to Marianini's result most clearly says, that any order must be considered in relation only to that *liquid employed in the experi*ments from which the order is derived[4]

2011. I have pursued this subject in relation to several solutions taking the precautions before referred to (1917, &c), and find that no such single order as that just referred to can be maintained Thus nickel is negative to an-

[1] *Elements of Chemical Philosophy* p 149
[2] *Annales de Chimie*, 1828 XXXVII p. 232.
[3] *Ibid*., p 235 [4] *Ibid*., p. 243.

timony and bismuth in strong nitric acid, it is positive to antimony and bismuth in dilute nitric acid, it is positive to antimony and negative to bismuth in strong muriatic acid, it is positive to antimony and bismuth in dilute

sium

2012 In further illustration of this subject I will take ten metals, and give their order in seven different solutions

1992, 2006, 2063), and yet never showing a case of the production of a current by contact alone, i e, unaccompanied by chemical action

2015 On the other hand, how simply does the chemical theory of excitement of the current represent the facts! as far as we can yet follow them they go hand in hand Without chemical action no current, with the changes of chemical action, changes of current, whilst

Dilute nitric acid	Dilute sulphuric acid	Muriatic acid	Strong nitric acid	Solution of caustic potassa	Colourless hydrosulphuret of potassium	Yellow hydrosulphuret of potassium
1 Silver	1 Silver	3 Antimony	5 Nickel	1 Silver	6 Iron	6 Iron
2 Copper	2 Copper	1 Silver	1 Silver	5 Nickel	5 Nickel	5 Nickel
3 Antimony	3 Antimony	5 Nickel	3 Antimony	2 Copper	4 Bismuth	4 Bismuth
4 Bismuth	4 Bismuth	4 Bismuth	2 Copper	6 Iron	8 Lead	3 Antimony
5 Nickel	5 Nickel	2 Copper	4 Bismuth	4 Bismuth	1 Silver	8 Lead
6 Iron	6 Iron	6 Iron	6 Iron	8 Lead	3 Antimony	1 Silver
7 Tin	8 Lead	8 Lead	7 Tin	3 Antimony	7 Tin	7 Tin
8 Lead	7 Tin	7 Tin	8 Lead	9 Cadmium	2 Copper	9 Cadmium
9 Cadmium	9 Cadmium	9 Cadmium	10 Zinc	7 Tin	10 Zinc	2 Copper
10 Zinc	10 Zinc	10 Zinc	9 Cadmium	10 Zinc	9 Cadmium	10 Zinc

2013 The dilute nitric acid consisted of one

of one volume strong solution and one volume water The strong nitric acid was pure, and of specific gravity 1 48 Both strong and weak solution of potassa gave the same order The yellow sulphuret of potassium consisted of one

which it afterwards acquires

2014 The displacements appear to be most

ductors or even of acids alkalies, &c, as d s tinct classes of such conductors, apart from their pure chemical relations But how can the contact theory account for these results? To meet such facts it must be bent about in the most extraordinary manner, following all the contortions of the string of facts (1874, 1956,

by the contact of the bodies produced, as the chemical actions producing these decay or are exhausted, the consequent result being well seen in the effect of the investing fluids pro-

Peroxide of lead,
Peroxide of manganese,
Oxide of iron
PLUMBAGO,
Rhodium
Platinum
Gold
Antimony,
Silver,
Copper
Zinc

in which plumbago is the neutral substance, those in italics are active at the cathode, and those in Roman characters at the anode. The

upper are of course negative to the lower. To make such lists as complete as they will shortly require to be, numbers expressive of the relative exciting force, counting from the zero point, should be attached to each substance.

¶ vii. *Active Voltaic Circles and Batteries without Metallic Contact*

2017. There are cases in abundance of electric currents produced by pure chemical action, but not one undoubted instance of the production of a current by pure contact. As I conceive the great question must now be settled by the weight of evidence, rather than by simple philosophic conclusions (1799), I propose adding a few observations and facts to show the number of these cases, and their force. In the Eighth Series of these *Researches*[1] (April, 1834) I gave the first experiment, that I am aware of, in which chemical action was made to produce an electric current and chemical decomposition at a distance, in a simple circuit, without any contact of metals (880, &c.). It was further shown, that when a pair of zinc and platinum plates were excited at one end of the dilute nitrosulphuric acid (880), or solution of potash (884), or even in some cases a solution of common salt (885), decompositions might be produced at the other end, of solutions of iodide of potassium (900), protochloride of tin (901), sulphate of soda, muriatic acid, and nitrate of silver (906), or of the following bodies in a state of fusion, nitre, chlorides of silver and lead, and iodide of lead (902, 906), no metallic contact being allowed in any of the experiments.

[1] *Philosophical Transactions*, 1834, p. 426.

2018. I will proceed to mention new cases, and first, those already referred to, where the action of a little dilute acid produced a current passing through the solution of the sulphuret of potassium (1831), or green nitrous acid (1844), or the solution of potassa (1854), for here no metallic contact was allowed, and chemical action was the evident and only cause of the currents produced.

2019. The following is a table of cases of similar excitement and voltaic action, produced by chemical action without metallic contact. Each horizontal line contains the four substances forming a circuit, and they are so arranged as to give the direction of the current, which was in all cases from left to right through the bodies as they now stand. All the combinations set down were able to effect decomposition, and they are but a few of those which occurred in the course of the investigation.

2020.

Iron	Dilute nitric acid	Platinum	Sulph. of potassium (1812)	Full current
Iron	Dilute nitric acid	Platinum	Red nitric acid	Full current
Iron	Dilute nitric acid	Platinum	Pale nitric acid, strong	Good
Iron	Dilute nitric acid	Platinum	Green nitrous acid	Very powerful
Iron	Dilute nitric acid	Platinum	Iodide of potassium	Full current
Iron	Dilute sulphuric acid	Platinum	Sulphuret of potassium	Full
Iron	Dilute sulphuric acid	Platinum	Red nitric acid	Good
Iron	Muriatic acid	Platinum	Green nitrous acid	Most powerful
Iron	Dilute muriatic acid	Platinum	Red nitric acid	Good
Iron	Dilute muriatic acid	Platinum	Sulphuret of potassium	Good
Iron	Solution of salt	Platinum	Green nitrous acid	Most powerful
Iron	Common water	Platinum	Green nitrous acid	Good
Zinc	Dilute nitric acid	Platinum	Iodide of potassium	Good
Zinc	Muriatic acid	Platinum	Iodide of potassium	Good
Cadmium	Dilute nitric acid	Platinum	Iodide of potassium	Good
Cadmium	Muriatic acid	Platinum	Iodide of potassium	Good
Lead	Dilute nitric acid	Platinum	Iodide of potassium	Good
Lead	Muriatic acid	Platinum	Iodide of potassium	Good
Copper	Dilute nitric acid	Platinum	Iodide of potassium	
Copper	Muriatic acid	Platinum	Iodide of potassium	
Lead	Strong sulphuric acid	Iron	Dilute sulphuric acid	Strong
Tin	Strong sulphuric acid	Iron	Dilute sulphuric acid	Strong
Copper	Sulphuret of potassium	Iron	Dilute nitric acid	Powerful
Copper	Sulphuret of potassium	Iron	Iodide of potassium	
Copper	Strong nitric acid	Iron	Dilute nitric acid	Very powerful
Copper	Strong nitric acid	Iron	Iodide of potassium	
Silver	Strong nitric acid	Iron	Dilute nitric acid	Strong
Silver	Strong nitric acid	Iron	Iodide of potassium	Good
Silver	Sulphuret of potassium	Iron	Dilute nitric acid	Strong
Tin	Strong sulphuric acid	Copper	Dilute sulphuric acid	

2021 It appears to me probable that any one of the very numerous combinations which can be made out of the following table, by taking one substance from each column and arranging them in the order in which the columns stand, would produce a current without metallic contact, and that some of these currents would be very powerful

Rhodium	Strong nitrous acid, or strong solution of sulphuret of potassium	Iron	Dilute nitric acid
Gold			Dilute sulphuric acid
Platinum			*Muriatic acid*
Palladium			Solution of vegetable acids
Silver			Iodide of potassium
Nickel			Iodide of zinc
Copper			Solution of salt
Lead			Many metallic solutions
Tin			
Zinc			
Cadmium			

2022 To these cases must be added the many in which one metal in a uniform acid gave currents when one side was heated (1942, &c)

acid one metal can be made either positive or

easily as with it

2024 That it is easy to construct batteries without metallic contact was shown by Sir Humphry Davy in 1801,[1] when he described

dilution, may be added to these

2025 Let $a\,b$, $a\,b$, $a\,b$ (Pl XIII *Fig* 6), represent tubes or other vessels, the parts at *a* containing strong nitric or sulphuric acid and the parts at *b* dilute acid of the same kind, then connect these by wires, *rods, or plates of* one metal only, being copper, iron, silver, tin, lead, or any of those metals which become positive and negative by difference of dilution in the

acid (1979, &c) Such an arrangement will give an effective battery

tion thus ⟶

2027 Strong and weak solutions of potassa

2028 If the arrangements be as in Pl XIII,

direction of the arrow If the metals be changed for each other, the acids remaining or the acids be changed the metals remaining the direction of the current will be reversed

¶ viii *Considerations of the Sufficiency of Chemical Action*

2029 Thus there is no want of cases in which chemical action alone produces voltaic currents (2017), *and if we proceed to look more closely* to the correspondence which ought to exist be-

arrangement of acid and alkali[1] is a most satisfactory proof that chemical action is abun-

(1905), in the solution of sulphuret of potassium, are excellent instances of the truth of this proposition

breaking it up Then two platinum wires, connected by a galvanometer, may be put into the

[1] *Annales de Chimie* 1827 XXXV p 122. *Bibliothèque Universelle* 1838 XIV, 129 171

acid, and one of them pressed against the piece of tin, yet without producing an electric current If, whilst matters are in this position, the tin be scraped under the acid by a glass rod or other non-conducting substance capable of breaking the surface, *the acid acts on the metal newly exposed, and produces a current*, but the action ceases in a moment or two from the formation of oxide of tin and an exhausted investing solution (1918), and the current ceases with it Each scratch upon the surface of the tin reproduces the series of phenomena

2033 The case of iron in strong nitric acid, which acts and produces a current at the first moment (1843, 1951, 2001), but is by that action deprived of so much of its activity, both chemical and electrical is also a case in point

2034 If lead and tin be associated in muriatic acid, the lead is positive at the first moment to the tin The tin then becomes positive, and continues so This change I attribute to the circumstance that the chloride of lead formed partly invests that metal and prevents the continuance of the action there, but the chloride of tin, being far more soluble than that of lead, passes more readily into the solution so that action goes on there, and the metal exhibits a permanent positive state

2035 The effect of the investing fluid already referred to in the cases of tin (1919) and cadmium (1918), some of the results with two metals in hot and cold acid (1966) and those cases where metal in a heated acid became negative to the same metal in cold acid (1963, &c), are of the same kind The latter can be beautifully illustrated by two pieces of lead in dilute nitric acid if left a short time, the needle stands nearly at 0°, but on heating either side, the metal there becomes negative 20° or more, and continues so as long as the heat is continued On cooling that side and heating the other, that piece of lead which before was positive now becomes negative in turn, and so on for any number of times

2036 *When the chemical action changes the current changes also* This is shown by the cases of two pieces of the same active metal in the same fluid Thus if two pieces of silver be associated in strong muriatic acid, first the one will be positive and then the other, and the changes in the direction of the current will not be slow as if by a gradual action, but exceedingly sharp and sudden So if silver and copper be associated in a dilute solution of sulphuret of potassium, the copper will be chemically active and positive, and the silver will remain clean, until of a sudden the copper will cease to act, the silver will become instantly covered with sulphuret, showing by that the commencement of chemical action there, and the needle of the galvanometer will jump through 180° Two pieces of silver or of copper in solution of sulphuret of potassium produce the same effect

2037 If metals be used which are inactive in the fluids employed, and the latter undergo no change during the time, from other circumstances, as heat, &c (1838, 1937), then no currents, and of course no such alterations in direction, are produced

2038 *Where no chemical action occurs no current is produced* This in regard to ordinary solid conductors, is well known to be the case, as with metals and other bodies (1867) It has also been shown to be true when fluid conductors (electrolytes) are used, in every case where they exert no chemical action though such different substances as acid alkalies and sulphurets have been employed (1843, 1853, 1825, 1829) These are very striking facts

2039 *But a current will occur the moment chemical action commences* This proposition may be well illustrated by the following experiment. Make an arrangement like that in Fig 14 the two tubes being charged with the same pure, pale strong nitric acid, the two platinum wires *p p* being connected by a galvanometer, and the wire *i*, of iron The apparatus is only another form of the simple arrangement (Pl XIII, Fig 9,) where in imitation of a former experiment (880), two plates of iron and platinum are placed parallel, but separated by a drop of strong nitric acid at each extremity Whilst in this state no current is produced in either apparatus, but if a drop of water be added at *b* Fig 9, chemical action commences and a powerful current is produced, though without metallic or any additional contact To observe this with the apparatus, (Pl XIII, Fig 8), a drop of water was put in at *b* At first there was no chemical action and no electric current though the water was there, so that contact with the water did nothing the water and acid were moved and mixed together by means of the end of the wire *i*, in a few moments proper chemical action came on, the iron evolving nitrous gas at the place of its action, and at the same time acquiring a positive condition at that part, and producing a powerful electric current

2040 *When the chemical action which either has or could have produced a current in one direction is reversed or undone, the current is reversed (or undone) also*

2041 This is a principle or result which most strikingly confirms the chemical theory of vol ta c excitement and is illustrated by many important facts Volta in the year 1802 [1] showed that crystallized *oxide of manganese* was highly negative to zinc and similar metals giving according to his theory electricity to the zinc at the point of contact Becquerel worked carefully at this subject in 1835 [2] and came to the conclusion, but reservedly ex pressed that the facts were favourable to the theory of contact In the following year De la Rive examined the subject [3] and shows to my satisfaction at least that the peroxide is at the

in the green nitrous acid originates a current and is negative to the platinum at the same time giving up oxygen and converting the ni trous acid into nitric acid a change eas ly shown by a common chemical experiment In

associated with platinum in solution of potash the addition of a little alcohol singularly favours the increase of the current for the same reason When the peroxide and platinum are associated with solution of sulphuret of potas sium the peroxide as might have been ex pected is strongly negative

2043 In 1835 M Muncke [4] observed the

made and divided into two portions one was

Univer-

311 and

tested by a solution of sulphuretted hydrogen and showed no signs of lead the other was

to contain plenty of lead

2044 The peroxide of lead is negative to platinum in solutions of common salt and pot

immersion

2045 The most powerful arrangement with peroxide of lead platinum and one fluid was obtained by using a solution of the yellow sul

an oxide being as platinum in the solution (1840) But if it be oxidized by exposure to air, or by being wetted and dried, or by being moistened by a little dilute nitric or sulphuric acid and then washed, first in solution of ammonia or potassa, and afterwards in distilled water and dried or if it be moistened in solution *of potassa, heated in the air, and then* washed well in distilled water and dried such iron associated with platinum and put into a solution of the sulphuret will produce a powerful current until *all* the oxide is reduced, the iron during the whole time being negative

2048 A piece of rusty iron in the same solution is powerfully negative So also is a platinum plate with a coat of protoxide, or peroxide, or native carbonate of iron on it (2045)

2049 This result is one of those effects which has to be guarded against in the experiments formerly described (1826, 1886) If what appears to be a clean plate of iron is put into a dilute solution of the sulphuret of potassium, it is first negative to platinum, then neutral, and at last generally feebly positive if it be put into a strong solution, it is first negative, and then becomes neutral continuing so It cannot be cleansed so perfectly with sand paper, but that when immersed it will be negative, but the more recently and well the plate has been cleansed the shorter time does this state continue This effect is due to the instantaneous oxidation of the *surface* of the *iron* during its momentary exposure to the atmosphere, and the *after reduction of this oxide by* the solution Nor can this be considered an unnatural result to those who consider the characters of iron Pure iron in the form of a sponge takes fire spontaneously in the air and a plate recently cleansed, if dipped into water, or breathed upon, or only exposed to the atmosphere, produces an instant smell of hydrogen The thin film of oxide which can form during a momentary exposure is, therefore quite enough to account for the electric current produced

2050 As a further proof of the truth of these explanations, I placed a plate of iron und[illegible] e surface of a solution [illegible] the [illegible] was then neutral or [illegible] slightly positive to platinum connected with it. Whilst in connection with the platinum it was again rubbed with the wood so as to acquire a fresh surface of contact, it did not become negative, but continued in the least degree positive, showing that the former negative current was only a temporary result of the coat of oxide which the iron had acquired in the air

2051 Nickel appears to be subject to the same action as iron, though in a much slighter degree All the circumstances were parallel and the proof applied to iron (2050) was applied to it also, with the same result

2052 So all these phenomena with protoxides and peroxides agree in referring the current produced to chemical action not merely by showing that the current depends upon the action, but also that the *direction* of the current depends upon the direction which the chemical affinity determines the exciting or electromotive anion to take And it is I think a most striking circumstance that these bodies which when they can and do act chemically produce currents, have not the least power of the kind when *mere contact only* is allowed (1869), *though they are excellent conductors of electricity*, and can readily carry the currents formed by other and more effectual means

2053 With such a mass of evidence for the efficacy and sufficiency of chemical action as that which has been given (1878, 2052), with so many current circuits without metallic contact (2017) and so many non-current circuits with (1867), what reason can there be for referring the effect in the joint cases where both *chemical action and contact occur*, to contact or to anything but the chemical force alone? *Such a reference appears to me most* unphilosophical it is dismissing a proved and active *cause to receive in its place one which is merely* hypothetical

¶ ix *Thermo-electric Evidence*

2054 The phenomena presented by that most beautiful discovery of Seebeck, thermo-electricity, has occasionally and, also, recently been adduced in proof of the electromotive influence of contact amongst the metals, and such like solid conductors[1] (1809, 1867) A very brief consideration is, I think, sufficient to show how little support these phenomena give to the theory in question

2055 If the contact of metals exert any exciting influence in the voltaic circuit, then we can hardly doubt that thermo-electric currents are due to the same force, i e, to disturbance, *by local temperature, of the balanced forces of* the different contacts in a metallic or similar

[1] See Fechner's words. *Philosophical Magazine*, 1838, XIII p 206

circuit Those who quote thermo effects as proofs of the effect of contact must, of course, admit this opinion

2056 Admitting contact force, we may then assume that heat either increases or diminishes the electromotive force of contact For if in Pl XIII, *Fig 10*, A be antimony and B bismuth, heat applied at x causes a current to pass in the direction of the arrow, if it be assumed that *bismuth in contact with antimony* tends to become positive and the antimony negative, then heat diminishes the effect, but if it be supposed that the tendency of bismuth is to become negative, and of antimony positive, then heat increases the effect How we are to decide which of these two views is the one to be adopted, does not seem to me clear, for nothing in the thermo-electric phenomena alone can settle the point by the galvanometer

2057 If for that purpose we go to the voltaic circuit, there the situation of antimony and bismuth ...

was long ago pointed out by Professor Cumming [1] how is it consistent with the contact theory of the voltaic pile?

2058 ...

sults will give the direction of contact force

the former When the colourless hydrosulphuret of potassium is used to complete the voltaic circle, the current is from bismuth to silver, and from silver to antimony at their points of contact, whilst, with strong muriatic acid precisely the reverse direction occurs for it is from silver to bismuth, and from antimony to silver at the junctions

2059 Again, by the heat series copper gives *a current to gold tin and lead give currents to* copper, rhodium or gold, zinc gives one to antimony, or iron, or even plumbago and ...

reverse of those produced by the same metals, when formed into voltaic circuits and excited by the ordinary acid solutions (2012)

2060 These, and a great number of other ...

sumed contact force being not only unlike thermo metallic contact, in not possessing a *balanced state in the complete circuit* at uniform temperatures, but, also, having no relation to it as to the *order* of the metals employed

which stands between tin and zinc thermo-electrically, not only must the same departure be required, but how great must the effect of this, its incongruous contact, be, to overcome ...

junction To be at all consistent with this simple and true relation, sulphuric acid should not be strongly energetic with iron or tin and weakly so with silver, as it is in the voltaic circuit, since these metals are not far apart in the thermo series nor should it be nearly alike to platinum and gold voltaically, since they are far apart in the thermo series

2062 Finally, in the thermo circuit there is that relation to heat which shows that for *every portion of electric force evolved, there is* a corresponding change in another force, or form of force, namely heat, able to account for it, this, the united experiments of Seebeck and Peltier have shown *But contact force is a force* which has to produce something from nothing, a result of the contact theory which can be *better stated a little further on* (2069, 2071, 2073)

2063 What evidence then for mere contact *excitement, derivable from the facts of thermo*-electricity, remains since the power must thus be referred to the acid or other electrolyte used (2060) *and made, not only to vary uncertainly* for each metal, but *to vary* also in direct conformity with the variation of chemical action (1874, 1956, 1992 2006, 2014)?

2064 *The contact theorist seems to consider* that the advocate of the chemical theory is called upon to account for the phenomena of thermo-electricity I cannot perceive that Seebeck's circle has any relation to the voltaic pile, and think that the researches of Becquerel[1] are quite sufficient to authorize that conclusion

¶ x *Improbable Nature of the Assumed Contact Force*

2065 *I have thus given a certain body of* experimental evidence and consequent conclusions, which seem to me fitted to assist in the *elucidation of the disputed point, in addition* to the statements and arguments of the great men who have already advanced their results and opinions in favour of the chemical theory *of excitement in the voltaic pile, and against* that of contact I will conclude by adducing a further argument founded upon the, to me, *unphilosophical nature of the force to which* the phenomena are, by the contact theory, referred

2066 It is assumed by the theory (1802) that where *two dissimilar metals (or rather* bodies) touch, the dissimilar particles act on each other, and induce opposite states I do not deny this, but on the *contrary* think that in many cases such an effect takes place between contiguous particles, as for instance, preparatory to action in common chemical phenomena, and also preparatory to that act of chemical combination which, in the voltaic circuit, causes the current (1738, 1743)

2067 *But the contact theory assumes that* these particles, which have thus by their mutual action acquired opposite electrical states, *can discharge these states one to the other*, and yet remain in the state they were first in, being *in every point* entirely unchanged by what has previously taken *place* It assumes also that the *particles*, being by their mutual *action* rendered plus and minus, can, whilst under this inductive action, discharge to particles of *like matter with themselves* and so produce a current

2068 This is in no respect consistent with *known actions If in relation to chemical phe*nomena we take two substances, as oxygen and hydrogen, we may conceive that two particles, *one of each*, being placed together and *heat applied*, they induce contrary *states in* their opposed surfaces, according, perhaps, to the view of Berzelius (1739), and that these *states becoming more and more exalted* end at last in a mutual discharge of the *forces*, the particles being ultimately found combined, and *unable to repeat the effect* Whilst they are under induction and *before the final action* comes on, they cannot spontaneously *lose* that state, but by removing the *cause* of the *increased* inductive effect, *namely the heat*, the effect itself can be lowered to its first condition If the acting particles are involved in the constitution of an electrolyte, then they can produce *current force* (921, 924) proportionate to the amount of chemical force *consumed* (868)

2069 But the *contact theory*, which is obliged, according to the *facts*, *to admit* that the acting particles are not changed (1802, 2067) (for otherwise it would be the chemical *theory*), *is constrained* to admit also, that the force which is able to make two *particles* assume a certain state in respect to each *other*, *is* unable to make them *retain* that state, and *so it virtually denies the great principle* in natural philosophy, that cause and *effect are equal* (2071) If a particle of platinum by *contact* with a particle of zinc willingly gives of its own *electricity to the zinc, because this* by its presence tends to make the platinum *assume a neg*ative state, why should the particle of platinum

[1] *Annales de Chimie* 1829, XLI, 355, XLVI, 275

[illegible]

fect of contact may take place through air and measurable distances),[1] for there a ball rendered negative by induction, will not take electricity from surrounding bodies, however thoroughly we may uninsulate it, and if we force electricity into it, it will, as it were be spurned back again with a power equivalent [illegible]

[illegible]

should not electricity go to the platinum *from the zinc*, which is as much in contact with it as its neighbouring platinum particles are? Or if the zinc particle in contact with the platinum tends to become positive why does not electricity flow to it from the zinc particles behind, as well as from the platinum?[2] There is no sufficient probable or philosophic cause assigned for the assumed action, or reason given why one or other of the consequent effects above mentioned should not take place and, as I have again and again said, I do not know of a single fact, or case of contact current, on which, in the absence of such probable cause, the theory can rest

2071 The contact theory assumes, in fact, that a force which is able to overcome powerful resistance as for instance that of the con [illegible]

shall go on for ever against a constant resistance, or only be stopped, as in the voltaic trough, by the ruins which its exertion has heaped up in its own course This would indeed be *a creation of power*, and is like no other force in nature We have many processes by which the form of the power may be so changed that an apparent *conversion* of one into another takes place So we can change chemical force into the electric current, or the current into chemical force The beautiful experiments of Seebeck and Peltier show the convertibility of heat and electricity, and others by Oersted and myself show the convertibility of electricity and magnetism But in no cases, not even those of the gymnotus and torpedo (1790), is there a pure creation of force a production of power without a corresponding exhaustion of something to supply it[3]

2072 It should ever be remembered that the chemical theory sets out with a power the existence of which is pre proved, and then follows its variations, rarely assuming anything which is not supported by some corresponding simple chemical fact The contact theory sets out with an assumption to which it adds others

2073 Were it otherwise than it is, and were the contact theory true, then, as it appears to me the equality of cause and effect must be denied (2069) Then would the perpetual mo- [illegible]

[1] *Memorie della Società Italiana in Modena* 1837 XXI 232 233 &c

[2] I have spoken for simplicity of expression as if one metal were active and the other passive in bringing about these induced states and not as the theory

tion also be ...

... go on producing mechanical effects for ever

Royal Institution December 26, 1839

NOTE

2074 In a former series (925, &c) I have said that I do not think any part of the elec...

... are not parts of electrolytes

This I would correct for I think that Becquerel's pile is a *perfect proof* that when acid and alkali combine an electric current is produced [1]

I perceive that Dr Mohr of Coblentz appears to have shown that *it is only nitric acid* which amongst acids can in combining with alkalies produce an electric current [2]

[1] *Bibliothèque Universelle* 1838 XIV 129 171 *Comptes Rendus* I p 455 *Annales de Chimie* 1827 XXXV 122

[2] *Philosophical Magazine* 1838 XIII, p. 382 or Poggendorf's *Annalen* XLII p 76.

For myself, I had made exception of the hydracids (929) on theoretical grounds I had also admitted that oxyacids when in solution might in such cases produce small currents of electricity (928 and *Note*), and Jacobi says that in Becquerel's improved acid and alkaline pile, it is not above a thirtieth part of the whole power which appears as current But I now wish to say that though in the voltaic battery dependent for its power on the oxidization of zinc, I do not think that the *quantity* of electricity is at all increased or affected by the com...

... the nature of compound electrolytes[1] ties together the electrolyzation of a salt and the water in which it is dissolved, in such a manner ...

... a similar connection between the water and the salt formed must exist and I have little doubt that the joint action of water, acids, and bases, in Becquerel's battery, in Daniell's electrolyzations, and at the zinc in the ordinary active pile, are, in principle, closely connected together

[1] *Philosophical Transactions* 1839 p 97

EIGHTEENTH SERIES

§ 25 *On the Electricity Evolved by the Friction of Water and Steam against Other Bodies*

RECEIVED JANUARY 26, READ FEBRUARY 2, 1843

2075 Two years ago an experiment was described by Mr Armstrong and others,[1] in which the issue of a stream of high pressure steam into the air produced abundance of electricity The source of the electricity was not ascertained, but was supposed to be the evaporation or change ...

dir...

at ...

working upon the subject, and though I perceive many other important points, worthy its attention

2076 The apparatus I have used was not competent to f...

hig...

pur...

fect

...

... feet long was at

[1] *Philosophical Magazine* 1840, XVII, pp. 370, 452, &c.

[1] *Ibid.*, 1843 XXII p 1

steam-globe, and to this globe, by its mouthpiece, could be attached various forms of apparatus, serving as vents for the issuing steam [1] Thus a cock could be connected with the steam-globe, and this cock be used as the experimental steam passage, or a wooden tube could be screwed in, or a small metal or glass tube put through a good cork, and the cork screwed in, and in these cases the steam way of the [illegible]

tube terminated by a *metal funnel*, and of a cone advancing by a screw more or less into the funnel, so that the steam as it rushed forth [illegible]

2078 Another terminal piece consisted of a [illegible]

2079 In another terminal piece a small cylindrical chamber was constructed (Pl XIV, *Fig 4*) into which different fluids could be introduced, so that, when the cocks were opened, the steam passing on from the steam globe (2076) should then enter this chamber and take up anything that was there, and so proceed [illegible]

2080 The pressure at which I worked with the steam [illegible]

the abundant escape of the results of the combustion

2082 When the issuing steam produces electricity, there are two ways of examining the effect either the insulated boiler may be observed, or the steam may be examined but these states are always contrary one to the other I attached to the boiler both a gold leaf and a discharging electrometer, the first showed any charge short of a spark, and the second by the number of sparks in a given time carried on the measurement of the electricity evolved The state of the steam may be observed either by [illegible]

ing a puff of it near an electrometer when it acts by induction, or by putting wires and [illegible]

strong has observed, than to go for the electricity to the steam itself and in this paper I shall give the state of the former, unless it be otherwise expressed

2083 Proceeding to the cause of the excitation, I may state first that I have satisfied myself it is not due to evaporation or condensation, nor is it affected by either the one or the other When the steam was at its full pressure, if the valve were suddenly raised and taken out, no electricity was produced in the boiler, though the evaporation was for the time very great Again, if the boiler were charged by excited resin before the valve was opened, the opening of the valve and consequent evaporation did not affect this charge Again, having obtained the power of constructing steam passages which should give either the positive or the negative, or the neutral state (2102, 2110, 2117), I could attach these to the steam way, so as to make the boiler either positive or negative, or neutral at pleasure with the same steam, and whilst the evaporation for the whole time continued the same So that the excitation of electricity is clearly independent of the evaporation or of the change of state

[illegible]

(2102) (Pl XIV, *Fig 6*) soaked in water, and screwed into the steam globe If with either of these arrangements, the steam-globe (*Fig 1*) be empty of water, so as to catch and retain

[1] This globe and the pieces of apparatus are represented upon a scale of one-fourth in the Plate belonging to this paper

[2] Mr Armstrong has also ascertained that water is essential to a high development. *Phil Mag.*, 1843, Vol. XXII, p 2

PLATE XIV

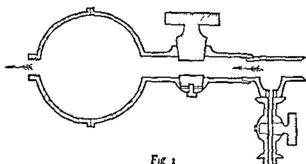


Fig 1

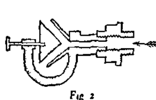


Fig 2

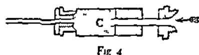
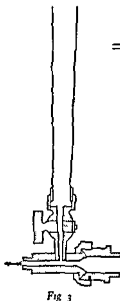


Fig 4



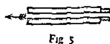


Fig 5

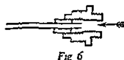


Fig 6

Fig 3

Description of the Apparatus represented in section, and to a scale of one-fourth

Fig 1 The steam-globe (2076), principal steam-cock, and drainage-cock to remove the water condensed in the pipe The current of steam, &c. travelled in the direction of the arrow-heads

fitting into the steam-globe.

that which is condensed from the steam, then after the first moment (2089), and when the apparatus is hot, the issuing steam excites no electricity, but when the steam-globe is filled up so far that the rest of the condensed water is swept forward with the steam, abundance of electricity appears If then the globe be emptied of its water, the electricity ceases, but

steam carries forward against the surrounding

ing or interposed body, will produce a very sensible proportion of electricity

2086 Of the many circumstances affecting this evolution of electricity, there are one or two which I ought to refer to here Increase of pressure (as is well illustrated by Mr Armstrong s experiments) greatly increases the effect, simply by rubbing the two exciting substances more powerfully together Increase of pressure will sometimes change the positive power of a passage to negative, not that it has power of itself to change the quality of the passage, but as will be seen presently (2108), by carrying off that which gave the positive

current of water and steam), may, no doubt, by increase of pressure be again developed and exalted

2087 The shape and form of the exciting

against which they rub

2088 When the mixed steam and water pass through a tube or stop-cock (2076), they may issue, producing either a hissing smooth sound, or

passage, and which again causes the better

electricity ceases to be evolved If, then, whilst the steam is issuing, the cock be cooled by an

no first effect On this principle, I have made an exciting passage by surrounding one part of an exit tube with a little cistern, and putting spirits of wine or water into it

¹ Messrs Armstrong and Schafhaeutl have both observed the coincidence of certain sounds or noises with the evolution of the electricity

water which the steam-globe retained as a con-

stances (2099) remained entirely unexcited and

globe, varying from extreme weakness to considerable sourness, I used tubes and cones of zinc, but could obtain *no trace* of electricity Chemical action, therefore, appears to have nothing to do with the excitement of electricity by a current of steam

2107 Having thus given the result of the

all other substances, even cat's hair and oxalate of lime (2131) We shall find hereafter, that we have power, not merely to prevent the jet of steam and water from becoming positive, as by using an ivory tube (2102), but also of reducing its own power when passing through or against such substances as wood, metal, glass, &c Whether, with a jet so reduced, we shall still find amongst the bodies above mentioned (2099) some that can render the stream positive and others that can make it negative, is a question yet to be answered

2108 Advancing in the investigation, a new point was to ascertain what other bodies, than

was instantly changed, the boiler became powerfully positive, and the jet of steam, &c, as

troduced into the steam-globe with the water, instantly made the boiler positive and the issu-

formed into a ring, moistened with oil of turpentine and placed in the box, as long as a trace of the fluid remained in the box the boiler was positive and the issuing stream negative

2110 Thus the positive or negative state can

the passage of the steam soon causes the new effect to cease, yet with the power of renewing it in an instant

2111 With olive oil the same general phenomena were observed, i e, it made the stream of steam, &c, *negative*, and the substance rubbed by it *positive* But from the comparative fixedness of oil, the state was much more permanent, and a very little oil introduced into the steam-globe (2076), or into the chamber C (2079), or into the exit tube, would make the boiler positive for a long time It required, however, that this oil should be in such a place that the steam stream, after passing by it, should rub against other matter Thus, on using a

dinary negative state, as with pure water, and the issuing steam was positive

2112 Water is essential to this excitation by fixed oil, for when the steam globe was emptied of water, and yet oil left in it and in the passages, there was no excitement The first effect (2089) it is true was one of excitement, and it rendered the boiler positive, but that was an effect due to the water condensed in the passage, combined with the action of the oil Afterwards when all was hot, there was no evolution of electricity

2113 I tried many other substances with the chamber C and other forms of apparatus, using the wet wooden tube (2102) as the place and substance by which to excite the steam stream Hog's-lard, spermaceti, bees'-wax, castor oil, resin applied dissolved in alcohol, these, with olive-oil, oil of turpentine, and oil of laurel, all rendered the boiler positive, and the issuing steam negative Of substances which seemed

to have the reverse power, it is doubtful if there are any above water. Sulphuret of carbon, naphthaline, sulphur, camphor, and melt-

gas liquid, naphtha and caoutchoucine, gave occasionally variable results, as if they were the consequence of irregular and complicated

stream, exchanging its mechanical action from rubbed to rubber, it should give rise to variable effects, this, I think, was the case with the cone and resin before referred to (2097)

2114 The action of salts, acids, &c , when present in the water to destroy its effect, I have already referred to (2090, &c) In addition, I may note that sulphuric ether, pyroxylic spirit, and boracic acid did the same

2115 Alcohol seemed at the first moment to render the boiler positive Half alcohol and half water rendered the boiler negative, but much less so than pure water

2116 It must be considered that a substance having the reverse power of water, but only in a small degree, may be able to indicate that property merely by diminishing the power of water This diminution of power is very differ-

2117 When it is required to render the issuing steam permanently negative, the object is very easily obtained A little oil or wax put into the steam-globe (2076), or a thick ring of string or canvas soaked in wax, or solution of

shall neither become electric, nor cause that to be electrified against which it rubs

2118 We have arrived, therefore, at three

variable Other circumstances also powerfully affect it occasionally (2144)

2120 A very little oil in the rubbing passages produces a great effect, and this at first was a source of considerable annoyance, by the continual occurrence of unexpected results, a portion may lie concealed for a week together in the thread of an unsuspected screw, and yet

sage, which was in some degree persistently

steam had removed that (2110), the passage appeared to be perfectly clear and good and in its normal condition

2121 I now tried the effect of oil, &c , when a little saline matter or acid was added to the water in the steam-globe (2090, &c), and found that when the water was in such a state as to have no power of itself, still oil of turpentine or, oil, or resin in the box C, showed their power, in conjunction with such water, of rendering the boiler positive, but their power appeared to be reduced increase of the force of steam, as in all other cases, would, there is little doubt,

2122 We have seen that the action of such bodies as oil introduced into the jet of steam changed its power (2108), but it was only by experiment we could tell whether this change

positive, there was not one exception

2123 The remarkable power of oil, oil of turpentine, resin, &c , when in very small quan-

tity, to change the exciting power of water, though as regards some of them (2112) they are inactive without it, will excuse a few theoretical observations upon their mode of action In the first place it appears that steam alone cannot by friction excite the electricity,

and are excited, just as when the hand is passed over a rod of shellac When olive oil or oil of turpentine is present, these globules are, I believe, virtually converted into globules of these bodies, and it is no longer water, but the new fluids which are rubbing the rubbed bodies

2124 The reasons for this view are the following If a splinter of wood dipped in olive oil or oil of turpentine touch the surface of water, a pellicle of the former instantly darts and spreads over the surface of the latter Hence it is pretty certain that every globule of water passing through the box C, containing olive oil or oil of turpentine, will have a pellicle over

not quite able to pull the first pan from the water, it will give a rough measure of the cohesive force of the water If now the oily splinter of wood touch any part of the clean surface of the water in the dish, not only will it spread over the whole surface, but cause the pan to

oil facilitates the separation of the water into parts by a mechanical force not otherwise sufficient, and invests these parts with a film of its own substance

2125 All this must take place to a great extent in the steam passage the particles of water there must be covered each with a film of oil The tenuity of this film is no objection to the supposition, for the action of excitement is

of itself should deeply injure the power of olive-oil or resin, and hardly touch that of oil of turpentine (2121), for the olive-oil or resin would no longer form a film over it but dissolve in it on the contrary the oil of turpentine would form its film

2127 That resin should produce a strong ef

Under the circumstances water has much more attraction for the wood rubbed than oil has, for in the steam-current, canvas, wood, &c, which have been well soaked in oil for a long time are quickly dispossessed of it, and found saturated with water In such case the effect would still be to increase the positive state of the substance rubbed, and the negative state of the issuing stream

2129 Having carried the experiments thus far with steam, and having been led to consider the steam as ineffectual by itself, and merely the mechanical agent by which the rubbing particles were driven onwards, I proceeded to experiment with compressed air [1] For this purpose I used a strong copper box of the capacity of forty-six cubic inches, having two stop-cocks, by one of which the air was always forced in, and the other retained for the exit aperture The box was very carefully cleaned out by caustic potash Extreme care was taken (and required) to remove and avoid oil, wax, or resin about the exit apertures The air was forced into it by a condensing syringe, and in certain cases when I required dry air, four or

was used in each blast was 100 cubic i

was very difficult to deprive this air of the smell of oil which it acquired in being pumped through the condensing syringe

2130 I will speak first of undried common air when such compressed air was let suddenly

[1] Mr Armstrong has also employed air in much larger quantities *Philosophical Magazine* 1841 Vol. XVIII pp 133 328

out against the brass or the wood cone (2077), it rendered the cone negative exactly as the steam and water had done (2097) This I attributed to the particles of water suddenly con-

[illegible]

face of the wood and metal The electricity here excited is quite consistent with that evolved by steam and water but the idea of that being due to evaporation (2083) is in striking contrast with the actual conden sation here

2131 When however common air was let out against ice it rendered the ice *positive* again and again and that in alternation with the negative effect upon wood and metal This is strongly in accordance with the high positive position which has already been assigned to water (2107)

2132 I proceeded to experiment with dry air (2129), and found that it was in all cases quite *incapable* of exciting electricity against wood or sulphur, or brass in the form of cones (2077, 2097) yet if, in the midst of these experiments, I let out a portion of air immedi-

[illegible]

was due to the condensed water, and that neither *air alone* nor *steam alone* can excite these bodies, wood brass, &c , so as to produce the effect now under investigation

2133 In the next place the box C was attached to this air apparatus and experiments made with different substances introduced into it (2108), using common air as the carrying vehicle

2134 With distilled water in C, the metal cone was every now and then rendered nega tive, but more frequently no effect was produced The want of a continuous jet of air sadly interfered with the proper adjustment of the

[illegible]

any traces of electricity

2136 With oil of turpentine only in box C,

2137 In the same manner olive-oil and water in C, or resin in alcohol and water in C ren dered the cone positive exactly as if these substances had been carried forward in their course by steam

2138 Although the investigation as respects the steam stream may here be considered as finished I was induced in connection with the subject to try a few experiments with the air current and dry powders *Sulphur* in powder (sublimed) rendered both metal and wood, and even the sulphur cone negative only once did it render metal positive *Powdered resin* generally rendered metal negative and wood positive, but presented irregularities and often gave *two states in the same experiment* first diverging the electrometer leaves and yet at the end

[illegible]

fluo-silicic acid by water, gave very constant

[illegible]

rise to two or three observations In the first place the high degree of friction occurring be-

[illegible]

stances which, with others present, tend to cause these variable results

2140 Sulphur is nearly constant in its results and silica very constant yet their states are the reverse of those that might have been expected Sulphur in the lump is rendered negative whether rubbed against wood or any of the metals which I have tried, and renders them *positive* (2141), yet in the above experiments it almost always made both negative

Silica, in the form of a crystal, by friction with wood and metals renders them *negative*, but applied as above, it constantly made them

have not had time to investigate the subject

2141 In illustration of the effect produced by steam and water striking against other bodies, I rubbed these other substances (2099) together in pairs to ascertain their order, which was as follows

1 Catskin or bearskin	8 Linen canvas	
2 Flannel	9 White silk	
3 Ivory	10 The hand	Iron
4 Quill	11 Wood	Copper
5 Rock-crystal	12 Lac	Brass
6 Flint glass	13 Metals—	Tin
7 Cotton	14 Sulphur	Silver
		Platinum

Any one of these became negative with the substances above, and positive with those beneath it There are however many exceptions to this general statement thus one part of a catskin is very negative to another part, and even to rock crystal different pieces of flannel also differ very much from each other

between the folds of the same canvas will be strongly positive, and these effects alternate, so that it is easy to take away the one state in a moment by the degree of friction which produces the other state When a piece of flannel is halved and the two pieces drawn across each other, the two pieces will have different states irregularly, or the same piece will have both states in different parts, or sometimes both pieces will be negative, in which case, doubtless, air must have been rendered positive, and then dissipated

2143 Ivory is remarkable in its condition It is very difficult of excitement by friction with the metals, much more so than linen, cotton, wood, &c , which are lower in the scale than it (2141), and withal are much better conductors, yet both circumstances would have led to the expectation that it would excite better than them when rubbed with metals This property

fixed in a cork (2076) for many experiments with oil, resin, &c , it at last took up such a state as to give not merely a non-exciting passage for the steam, but to exert upon it a nullifying effect, for the jet of steam and water pass-

quite clean, and was afterwards soaked in alcohol to remove any resin, but it retained this peculiar state

being, I believe, friction, it has no effect in producing and is not connected with, the general electricity of the atmosphere also, that as far

NINETEENTH SERIES[1]

§ 26 *On the Magnetization of Light and the Illumination of Magnetic Lines of Force*[2] ¶ i. *Action of Magnets on Light* ¶ ii. *Action of Electric Currents on Light* ¶ iii *General Considerations*

RECEIVED NOVEMBER 6, READ NOVEMBER 20, 1845

¶ i *Action of Magnets on Light*

2146 I HAVE long held an opinion, almost amounting to conviction, in common I believe with many other lovers of natural knowledge, that the various forms under which the forces of matter are made manifest have one common origin, or, in other words, are so directly related and mutually dependent, that they are convertible, as it were, one into another, and possess equivalents of power in their action[3] In modern times the proofs of their convertibility have been accumulated to a very considerable extent, and a commencement made of the determination of their equivalent forces

2147 This strong persuasion extended to the powers of light, and led, on a former occasion, to many exertions, having for their object the discovery of the direct relation of light and electricity, and their mutual action in bodies subject jointly to their power,[4] but the results were negative and were afterwards confirmed, in that respect, by Wartmann[5]

osophical considerations, and, therefore, I recently resumed the inquiry by experiment in a

the detail of many unproductive experiments, I will describe as briefly and clearly as I can

2149 But before I proceed to them, I will define the meaning I connect with certain terms which I shall have occasion to use thus, by *line of magnetic force*, or *magnetic line of force*,

forming concentric circles round an electric current By *line of electric force*, I mean the force exerted in the lines joining two bodies, acting on each other according to the principles of static electric induction (1161, &c), which may also be either in curved or straight lines By a *diamagnetic*, I mean a body through

reflexion from a surface of glass, and the polarized ray passed through a Nichol's eye-piece revolving on a horizontal axis, so as to be easily examined by the latter. Between the polarizing mirror and the eyepiece two powerful electromagnetic poles were arranged, being either the

[1] *Philosophical Transactions* 1846 p 1
[2] The title of this paper has I understand led

[4] *Philosophical Transactions* 1834 F... *Researches* 951-955
[5] *Archives de l'Électricité* II, pp 596

poles of a horseshoe magnet, or the contrary poles of two cylinder magnets, they were separated from each other about 2 inches in the

lines of force (2149) After that, any transparent substance placed between the two poles,

2151 Sixteen years ago I published certain experiments made upon optical glass,[1] and described the formation and general characters of one variety of heavy glass which, from its materials, was called silicated borate of lead It was this glass which first gave me the discovery of the relation between light and magnetism, and it has power to illustrate it in a degree beyond that of any other body, for the sake of perspicuity I will first describe the phenomena as presented by this substance

2152 A piece of this glass, about 2 inches square and 0 5 of an inch thick, having flat and polished edges, was placed as a *diamagnetic* (2149) between the poles (not as yet magnetized by the electric current), so that the polarized ray *should pass through its length*, the glass acted as air, water, or any other indifferent substance would do, and if the eyepiece were previously turned into such a position that the polarized ray was extinguished, or rather the image produced by it rendered invisible, then the introduction of this glass made no alteration in that respect In this state of circumstances the force of the electro-magnet

and upon any occasion, showing a perfect dependence of cause and effect

2153 The voltaic current which I used upon this occasion, was that of five pair of Grove s

see it with a weak magnet

2154 The character of the force thus impressed upon the diamagnetic is that of *rotation*

this further motion is to the right- or left hand

2155 When the pole nearest to the observer was a marked pole, i e , the same as the north end of a magnetic needle, and the farther pole was unmarked, the rotation of the ray was right-handed, for the eye-piece had to be turned to the right-hand, or clock fashion, to overtake the ray and restore the image to its first condition When the poles were reversed which was instantly done by changing the direction of the electric current, the rotation was changed also and became left handed, the alteration *being to an equal degree in extent* as before The direction was always the same for the same *line of magnetic force* (2149)

2156 When the diamagnetic was placed in the numerous other positions, which can easily be conceived, about the magnetic poles, results were obtained more or less marked in extent,

as far as is necessary, hereafter

2157 The same phenomena were produced in the silicated borate of lead (2151) by the action of a good ordinary steel horseshoe mag-

over light

2158 Two magnetic poles were employed end ways, i e , the cores of the electro-magnets

fect was the same.

2159 One magnetic pole only was used, that being one end of a powerful cylinder electro-

magnet When the heavy glass was beyond the magnet, being close to it but between the magnet and the polarizing reflector, the rotation was in one direction, dependent on the nature

the contrary direction to what it was before,

that the *magnetic curves* were no longer passing through the glass parallel to the ray of polarized light, but rather perpendicular to it, then no effect was produced These particularities may be understood by reference to *Fig 1*,

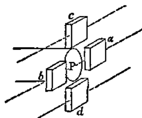


Fig 1

with the letters N and S, to represent the poles of a magnet, the line joining these letters may be considered as a magnetic line of force, and further, if a line be traced round the cylinder with arrow-heads on it to represent direction, as in *Fig 2*, such a simple model, held up before the eye, will express the whole of the law, and give every position and consequence of direction resulting from it.

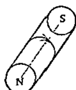


Fig 2

If a watch be considered as the diamagnetic, the north pole of a magnet being imagined against the face, and a south pole against the back, then the motion of the hand will indicate the direction of rotation which a ray of light undergoes by magnetization

2162 I will now proceed to the different circumstances which affect, limit, and define the extent and nature of this new power of action on light

three pieces, the greater was the rotation of

side of the course of the ray made any difference in the effect of that part through which the ray passed

2164 The power of rotating the ray of light *increased* with the intensity of the magnetic lines of force This general effect is very easily

the magnetism is right- or left-handed (2231)

2166 I could not perceive that this power was affected by any degree of motion which I was able to communicate to the diamagnetic, whilst jointly subject to the action of the magnetism and the light

2167 The interposition of copper, lead, tin, silver, and other ordinary non magnetic bodies in the course of the magnetic curves either between the pole and the diamagnetic, or in other positions, produced no effect either in kind or degree upon the phenomena

2168 Iron frequently affected the results in a very considerable degree, but it always appeared to be either by altering the direction of the magnetic lines or disposing within itself of their force Thus when the two contrary poles were on one side of the polarized ray (2150), and the heavy glass in its best position between them and in the ray (2152), the bringing of a large piece of iron near to the glass on the other side of the ray, caused the power of the diamagnetic to fall This was because certain lines of magnetic force which at first passed through the glass parallel to the ray, now crossed the glass and the ray the iron giving two contrary poles opposite the poles of the magnet, and thus determining a new course for a certain portion of the magnetic power, and that across the polarized ray

2169 Or if the iron, instead of being applied on the opposite side of the glass were applied on the same side with the magnet, either near it or in contact with it, then, again, the power of the diamagnetic fell, simply because the power of the magnet was diverted from it into a new direction These effects depend much of course on the intensity and power of the magnet, and on the size and softness of the iron

2170 The electro-helices (2190) without the iron cores were very feeble in power, and indeed hardly sensible in their effect With the iron cores they were powerful, though no more electricity was then passing through the coils than before (1071) This shows, in a very simple manner, that the phenomena exhibited by light under these circumstances is directly connected with the magnetic form of force ... plied by the arrangement An... i occurred ...

t ... , ... im-
a ... rotation of the polarized ray does not rise up to its full lustre immediately, but increases for a couple of seconds, gradually acquiring its greatest intensity, on breaking the contact, it sinks instantly and disappears apparently at once The gradual rise in brightness is due to the time which the iron core of the magnet requires to evolve all that magnetic power which the electric current can develop in it, and as the magnetism rises in intensity, so does its effect on the light increase in power, hence the progressive condition of the rotation

2171 I cannot as yet find that the heavy glass (2151), when in this state, i e, with magnetic lines of force passing through it, exhibits any increased degree, or has any specific magneto-inductive action of the recognized kind I have placed it in large quantities, and in different positions, between magnets and magnetic needles, having at the time very delicate means of appreciating any difference between it and air, but could find none

2172 Using water, alcohol, mercury, and other fluids contained in very large delicate thermometer shaped vessels, I could not discover that any difference in volume occurred when the magnetic curves passed through them

2173 It is time that I should pass to a consideration of this power of magnetism over light as exercised, not only in the silicated borate of lead (2151), but in many other substances and here we perceive, in the first place, that if all transparent bodies possess the power of exhibiting the action, they have it in very different degrees, and that up to this time there are some that have not shown it at all

2174 Next we may observe that bodies which are exceedingly different to each other in chemical physical, and mechanical properties, develop this effect, for solids and liquids, acids, alkalies, oils, water, alcohol, ether, all possess the power

2175 And lastly, we may observe, that in all of them, though the degree of action may differ, still it is always the same in kind being a rotative power over the ray of light, and further, the direction of the rotation is, in every case, independent of the nature or state of the substance, and dependent upon the direction of the magnetic line of force, according to the law before laid down (2160)

2176 Amongst the substances in which this power of action is found, I have already distinguished the silico-borate of lead (2151) as eminently fitted for the purpose of exhibiting the phenomena I regret that it should be the best, since it is not likely to be in the possession of many, and few will be induced to take the

trouble of preparing it If made, it should be well annealed, for otherwise the pieces will have considerable power of depolarizing light, and then the particular phenomena under consideration are much less strikingly observed The *borate of lead*, however, is a substance much more fusible, softening at the heat of boiling oil, and therefore far more easily prepared in the form of glass plates and annealed, and it

2177 Whilst employing crystalline bodies as diamagnetics, I generally gave them that position in which they did not affect the polarized ray, and then induced the magnetic curves

ascertain the fact decisively Two specimens of transparent fluor, lent me by Mr Tennant, gave the effect

2178 Rock-crystal, 4 inches across, gave no indications of action on the ray, neither did smaller crystals, nor cubes about three fourths of an inch in the side, which were so cut as to have two of their faces perpendicular to the axis of the crystal (1692, 1693), though they were examined in every direction

2179 *Iceland spar* exhibited no signs of effect, either in the form of rhomboids, or of cubes like those just described (1695)

2180 *Sulphate of baryta, sulphate of lime*, and *carbonate of soda*, were also without action on the light

2181 A piece of fine clear *ice* gave me no ef-

sult was hardly to be expected

2183 In experiments with liquids, a very good method of observing the effect is to enclose them in bottles from 1½ to 3 or 4 inches in diameter, placing the

tween the magnetic poles (2150), and bringing the analysing eye-piece so near to the bottle that, by adjustment of the latter, its cylindri-

through the striæ and deformations of the glass, and the phenomena being looked for in this light are easily seen

2184 Water, alcohol, and ether, all show the effect, water most, alcohol less, and ether the least All the fixed oils which I have tried, including almond, castor, olive, poppy, linseed, sperm, olein from hog's lard, and distilled resin oil, produce it The essential oils of turpentine, bitter almonds, spike lavender, lavender, jessamine, cloves, and laurel, produce it Also naphtha of various kinds, melted spermaceti, fused sulphur, chloride of sulphur, chloride of arsenic, and every other liquid substance which I had at hand and could submit in sufficient bulk to experiment

2185 Of aqueous solutions I tried 150 or

substance caused no exception to the general result, for all the bodies showed the property It is indeed more than probable, that in all these cases the water and not the other substance present was the ruling matter The same general result was obtained with alcoholic solutions

I have tried the experiment with bottles 4

ender, of laurel, Canada balsam, alcoholic solution of camphor, alcoholic solution of camphor and corrosive sublimate, aqueous solutions of sugar, tartaric acid, tartrate of soda, tartrate of potassa and antimony, tartaric and boracic acid, and sulphate ... tated to th...

... ...turpentine, in one ... rotation was to the right-hand, *and in the other to the left* In all these cases, as already said (2165), the superinduced magnetic rotation was according to the general law (2160), and *without reference to the previous* power of the body

2188 Camphor being melted in a tube about an inch in diameter, exhibited high natural rotative force, but I could not discover that the magnetic curves induced additional force in it It may be, however, that the shortness of the ray length and the quantity of coloured light left, even when the eye-piece was adjusted to the most favourable position for darkening the image *produced by the* naturally rotated ray, rendered the small magneto-power of the camphor insensible

¶ ii *Action of Electric Currents on Light*

2189 From a consideration of the nature and position of the lines of magnetic and electric force, and the relation of a magnet to a current of electricity, it appeared almost certain that an electric current would give the same result of action on *light* as a magnet and, in the helix, would supply a form of apparatus in which great lengths of diamagnetics, and especially of such *bodies as appeared to be but little affected* between the poles of the magnet, might be submitted to examination and their effect exalted this expectation was, by experiment, realized

2190 Helices of copper wire were employed, three of which I will refer to The first, or *long helix*, was 0 4 of an inch internal diameter, the wire was 0 03 of an inch in diameter, and having gone round the axis from one end of the helix to the other, then returned in the same manner, *forming a coil 65 inches long, double in its* whole extent, and containing 1240 feet of wire

2191 The second, or *medium helix*, is 19 inches long, 1 87 inch internal diameter, and 3 inches external diameter The wire is 0.2 of an inch in diameter, and 80 feet in length, being disposed in the coil as two concentric spirals The electric current, in passing through it, is not divided, but traverses the whole length of the wire

2192 The third, or *Woolwich helix*, was made under my instruction for the use of Lieut-Colonel Sabine's establishment at Woolwich It is 20 5 inches long, 2.5 inches internal diameter, and 4 75 inches external diameter The wire is 0 17 of an inch in diameter, and 501 feet in length It is disposed in the coil in four concentric spirals connected end to end, so that the whole of the electric current employed passes through all the wire.

2193 The long helix (2190) acted *very feebly* on a magnetic needle placed at a little distance from it, the medium helix (2191) acted more *powerfully*, and the Woolwich helix (2192) very strongly, the same battery of ten pairs of Grove's plate being employed in all cases

2194 Solid bodies were easily subjected to the action of these electro-helices being for that purpose merely cut into the form of bars or prisms with flat and polished ends, and then introduced as cores into the helices For the purpose of submitting liquid bodies to the same action, tubes of glass were provided, furnished at the ends with caps, the cylindrical part of the cap was brass, and had a tubular aperture for the introduction of the liquids, but the end was a flat glass plate When the tube was intended to contain aqueous fluids, the plates were attached to the caps, and the caps to the tube by Canada balsam, when the tube had to contain alcohol, ether or essential oils, a thick mixture of powdered gum with a little water was employed as the cement

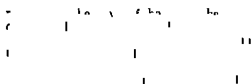
2195 The general effect produced by this form of apparatus may be stated as follows the tube within the long helix (2190) was filled *with distilled water and placed in the* line of the polarized ray, so that by examination through the eye piece (2150), the image of the lamp-flame produced by the ray could be seen through it Then the eyepiece was turned until the image of the flame disappeared, and, *afterwards*, the current of ten pairs of plates sent *through* the helix, instantly the image of the *flame re*appeared, and continued as long as the electric current was passing through the helix on *stopping the current the image disappeared* The light did not rise up gradually as in the case of electro-magn... These re... this expe... ...ay justly say that a ray ...ght is electrified and the electric forces illuminated

2196 The phenomena may be made more striking, by the adjustment of a lens of long focus between the tube and the polarizing mir-

ror or one of short focus between the tube and the eye and where the helix or the battery or the substance experimented with is feeble in power such means offer assistance in working out the effects but after a little experience they are easily dispensed with and are only useful as accessories in doubtful cases

2197 In cases where the effect is feeble it is more easily perceived if the Nichol eyepiece be adjusted not to the perfect extinction of the ray but a little short of or beyond that position so that the image of the flame may be but just visible Then on the exertion of the

is more easily perceived than if the eye began to observe from a state of utter darkness Such



2198 When the current was sent round the

done that the current passes from the zinc through the acid to the platinum in the same cell (663 667 1627) if such a current pass un

pressed When an electric current passes round a ray of polarized light in a plane perpendicular to the ray it causes the ray to revolve on its axis as long as it is under the influence of the current in the *same direction* as that in

beautiful A model is not wanted to assist the memory but if that already described (2161) be looked at the line round it will express at the same time the direction both of the current and the rotation It will indeed do much more for if the cylinder be considered as a piece of iron and not a piece of glass or other diamagnetic placed between the two poles N and S, then the line round it will represent the direction of the currents which according to Ampère s theory are moving round its particles or if it be considered as a core of iron (in place

formed if it were placed between the poles whose marks are affixed to its ends

helix I was able in some degree to ascertain the effect of length of the diamagnetic the force of the helix and current remaining the same The greater the column of water subjected to the action of the helix the greater

the electric current passed

2202 A short tube of water or a piece of heavy glass being placed in the axis of the Woolwich helix (2192) seemed to produce equal

2203 A tube of water as long as the Woolwich helix (2192) but only 0 4 of an inch in diameter was placed in the *helix parallel to*

tained when a larger tube of water was looked through whether the ray passed through the axis of the helix and tube, or near the side.

2204. If bodies be introduced into the helix possessing, naturally, rotating force, then the rotating power given by the electric current is *superinduced upon them* exactly as in the cases already described of magnetic action (2165, 2187)

2205 A helix, 20 inches long and 0 3 of an inch in diameter, was made of uncovered copper wire, 0 05 of an inch in diameter, in close spirals This was placed in a large tube of water, so that the fluid, both in the inside and at the outside of the helix, could be examined by the polarized ray When the current was sent *through* the helix the water within it received *rotating power but no trace of such an action on the light was seen on the outside of the helix*, even in the line most close to the uncovered wire

2206 The water was enclosed in brass and copper tubes, but this alteration caused not the slightest change in the effect

2207 The water in the brass tube was put into an *iron* tube, much longer than either the Woolwich helix or the brass tube, and quite one-eighth of an inch *thick in the side, yet when placed in the Woolwich helix (2192), the water* rotated the ray of light apparently as well as before

2208 An iron bar, 1 inch square and longer than the helix, was put into the helix, and the small water tube (2203) upon it The water exerted as much action on the light as before

2209 Three iron tubes, each 27 inches long and one-eighth of *an inch in thickness in the side, were selected of such diameters as to pass* easily one into the other, and the whole into the Woolwich helix (2192) The smaller one was supplied with glass ends and filled with water, and being placed in the axis of the Woolwich helix, had a certain amount of rotating power over the polarized ray The second tube was then placed over this, so that there was *now a thickness of iron equal to two-eighths of an inch between the water and the helix*, the water had *more* power of rotation than before On placing the third tube of iron over the two former, the power of the water *fell*, but was still very considerable These results are complicated, being dependent on the new condition which the character of iron gives to its action on the forces *Up to a certain amount, by increasing the development of magnetic forces, the helix and core, as a whole*, produce increased action on the water, but on the addition of more iron and the disposal of the forces through it, their action is removed in part from the water and the rotation is lessened

2210 Pieces of heavy glass (2151), placed in iron tubes in the helices, produced similar effects

2211 *The bodies which were submitted to the action of an electric current in a helix*, in the manner already described, *were as follows* heavy glass (2151, 2176), water, solution of sulphate of soda, solution of tartaric acid, alcohol, ether, and oil of turpentine, all of which were affected, and acted on light exactly in the manner described in relation to magnetic action (2173)

2212 I submitted *air* to the influence of these helices carefully and anxiously, but could not *discover any trace of action on the polarized ray of light I put the long helix (2190) into* the other two (2191, 2192), and combined them all into one consistent series, so as to accumulate power, but could not observe any effect of them on light passing through air

2213 In the use of helices, it is necessary to be aware of one effect, which might otherwise cause confusion and trouble At first, *the wire of the long helix (2190) was wound directly upon the thin glass tube which served to contain* the fluid When the electric current passed through the helix it raised the temperature of the metal and that gradually raised the temperature of the glass and the film of water in contact with it and so the cylinder of water, warmer at its surface than its axis, acted as a lens, gathering and sending rays of light to the eye, and continuing *to act for a time after the current was stopped By separating the* tube of water from the helix, and by other precautions, this source of confusion is easily avoided

2214 Another point of which the experimenter should be aware is the difficulty, and almost impossibility, of obtaining a piece of glass which, especially after it is cut, does not depolarize light When it does *depolarize difference of position makes an immense difference in the appearance* By always referring to the parts that do not depolarize, as the black cross, for instance, and by bringing the eye as near as may be to the glass, this difficulty is more or less overcome

2215 For the sake of supplying a *general indication of the amount of this induced rotating force in two or three bodies*, and without any pretence of offering correct numbers, I will give, generally, the result of a few attempts to measure the force, and compare it with the natural power of a specimen of oil of *turpentine* A very powerful electro-magnet was em-

ployed, with a *constant* distance between its poles of 2½ inches In this space was placed different substances, the amount of rotation of the eyepiece observed several times and the average taken, as expressing the rotation for the ray length of substance used But as the substances were of different dimensions the

(2163) The oil of turpentine was of course observed in its natural state, i e, without magnetic action Making water 1, the numbers were as follows

Oil of turpentine	11 8	
Heavy glass (2151)	6 0	
Flint glass	2 8	
Rock-salt	2 2	
Water	1 0	
Alcohol		less than water
Ether		*less than alcohol*

2216 In relation to the action of magnetic and electric forces on light I consider, that to know the conditions under which there is no

were, by means of coatings, the Leyden jar, and the electric machine, directed across the bodies, parallel to the polarized ray, and perpendicular to it both in and across the plane of polarization but without any visible effect The tension of a rapidly recurring, induced secondary current, was also directed upon the same bodies and upon water (*as an electrolyte*), but with the same negative result

2218 A polarized ray, powerful magnetic lines of force, and the electric lines of force (2149) just described, were combined in var

in two directions at right angles with each other, the ray was made to rotate, by altering the position of the polarizing mirror, that the plane of polarization might be varied the current was used as a continuous current, as a rapidly intermitting current, and as a rapidly alter-

sulphuric acid and solution of sulphate of soda, but still with negative results except in those positions where the phenomena already described were produced In one arrangement, the current passed in the direction of radii from a central to a circumferential electrode, the contrary magnetic poles being placed above and below and the arrangements were so good that when the electric current was passing the fluid rapidly rotated but a polarized ray sent horizontally across this arrangement was not at all affected Also, when the ray was sent

alone, the superinduction of the passage of the electric current made not the least difference in the effect upon the ray

¶ iii *General Considerations*

2221 Thus is established, I think for the

difficult in the present state of our knowledge *to express our expectation in exact terms and,* though I have said that another of the powers

of nature is, in these experiments, directly related to the rest, I ought, perhaps, rather to say that another form of the great power is distinctly and directly related to the other forms; or, that the great power manifested by particular phenomena in particular forms, is here further identified and recognized, by the direct relation of *its form of light to its forms of electricity and magnetism*

2222 *The relation existing between polarized* light and magnetism and electricity, is even more interesting than if it had been shown to exist with common light only It cannot but extend to common light, and, as it belongs to light made, in a certain respect, more precise in its character and properties by polarization, it collates and connects it with these powers, in that duality of character which they possess, and yields an opening, which before was wanting to us, for the appliance of these powers to the investigation of the nature of this and other radiant agencies

2223 Referring to the conventional distinction before made (2149), it may be again stated that it is the magnetic lines of force *only* which are effectual on the rays of light, and they *only (in appearance)* when *parallel to the ray of* light, or as they tend to parallelism with it As, in reference to matter not magnetic after the manner of iron, the phenomena of electric induction and electrolyzation show a vast superiority in the energy with which electric forces can act as compared to magnetic forces, so here, in another direction and in the peculiar *and correspondent effects which belong to magnetic forces, they are shown, in turn, to possess* great superiority, and to have their full equivalent of action on the same kind of matter

2224 The magnetic forces do not act on the ray of light directly and without the intervention of matter, but through the mediation of the substance in which they and the ray have a simultaneous existence, *the substances and the forces giving to and receiving from each other* the power of acting on the light This is shown by the non-action of a vacuum, of air or gases, and it is also further shown by the special degree in which different matters possess the property. That magnetic force acts upon the ray of light always with the same character of manner and *in the same direction, independent of the different varieties of substance,* or their states of solid or liquid, or their specific rotative force (2232), shows that the magnetic force and the light have a direct relation but that substances are necessary, and that these act in different degrees, shows that the magnetism and the light act on each other through the intervention of the matter.

2225 Recognizing or perceiving *matter* only by its powers, and knowing nothing of any imaginary nucleus, abstract from the idea of these powers, the phenomena described in this paper much strengthen my inclination to trust in the *views I have on a former occasion advanced in reference to its nature*[1]

2226 It cannot be doubted that the magnetic forces act upon and affect the internal constitution of the diamagnetic, just as freely in the dark as when a ray of light is passing through it, though the phenomena produced by light seem, as yet, to present the only means of observing this constitution and the change Further, any such change as *this must belong to opaque bodies, such as wood, stone,* and metal, for as diamagnetics, there is no distinction between them and those which are transparent The degree of transparency can at the utmost, in this respect, only make a distinction between the individuals of a class

2227 If the magnetic forces had made these bodies magnets, we could, by light, have examined a *transparent magnet,* and that would have been *a great help to our* investigation of the forces of matter But it does not make them magnets (2171), and therefore the molecular condition of these bodies, when in the state described, must be specifically distinct from that of magnetized iron, or other such matter, and must be *a new magnetic condition,* and as *the condition is a state of tension (manifested by its instantaneous return to the normal state* when the magnetic induction is removed), so the *force* which the matter in this state possesses and its mode of action, must be to us a *new magnetic force* or *mode of action* of matter.

2228 For it is impossible, I think, *to observe* and see the action of magnetic forces, *rising in intensity, upon a piece of heavy glass or a tube of water,* without also perceiving that the latter acquire properties which are not only *new* to the substance, but are also in subjection to very definite and precise laws (2160, 2199), and are equivalent in proportion to the magnetic forces producing them

2229 *Perhaps this state is a state of electric tension tending to a current,* as in magnets, according to Ampère's theory, the state is a state of *current.* When a core of iron is put into a helix, everything leads us to believe that currents of electricity are produced within it, which

[1] See p 850-855

rotate or move in a plane perpendicular to the axis of the helix If a diamagnetic be placed in the same position, it acquires power to make light rotate in the same plane The state it has received is a state of tension, but it has not passed on into currents, though the acting force and every other circumstance and condition are the same as those which do produce currents in iron nickel cobalt and such other matters as are fitted to receive them Hence the idea that there exists in diamagnetics under such circumstances a tendency to currents, is consistent with all the phenomena as yet de-

power, and make them pass into the common class of diamagnetics

2230 The present is, I believe, the first time that the molecular condition of a body, required to produce the circular polarization of

which possess the power naturally especially as some of the latter rotate to the right-hand and others to the left, and as in the cases of quartz and oil of turpentine, the same body chemically speaking being in the latter instance a liquid with particles free to move, presents different specimens some rotating one way and some the other

2231 At first one would be inclined to con-

ment of the mass Whichever way a ray of polarized light passes through this fluid it is rotated in the same manner and rays passing in

same oil of turpentine by the magnetic or electric forces it exists only in one direction i e, in a plane perpendicular to the magnetic line,

and being limited to this plane it can be changed in direction by a reversal of the direc

by the particles of the fluid the direction of the rotation produced by the induced condition is connected invariably with the direction of the magnetic line or the electric current and the condition is possessed by the particles of matter but strictly limited by the line or the current changing and disappearing with it

and *a b* a polarized ray of light If the ray proceed from *a* to *b*, and the eye be placed at *b* the rotation will *be right handed or* according to the direction expressed by the arrow heads on the circle *c* if the ray proceed from *b* to *a* and the eye be placed at *a* the rotation will still be right handed *to the observer* i e according to the direction indicated on the circle *d* Let now an electric current pass round the oil of turpentine in the direction indicated on the circle *c* or magnetic poles be placed so as to produce the same effect (2155) *the particles will* acquire a further rotative force (which no mo

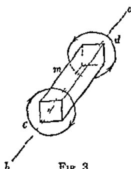


Fig 3

natural rotation as respects a ray passing from

2233 As respects the power of the oil of turpentine to rotate a ray in whatever direction it *is passing through the liquid, it may well be* that though all the particles possess the power of rotating the light, only those whose planes of rotation are more or less perpendicular to the ray affect it, and that it is the resultant or sum of forces in any one direction which is active in producing rotation But even then a striking difference remains, because the resultant in the same plane is not absolute in direction, but relative to the course of the ray, being in the one case as the circle *c*, and in the other as the circle *d*, *Fig 8* whereas the resultant of the magnetic or electric induction is absolute, and not changing with the course of the ray, being always either as expressed by *c* or else as *indicated by d*

2234 All these differences, however, will doubtless disappear or come into harmony as these investigations are extended, and their very existence opens so many paths, by which we may pursue our inquiries, more and more deeply, into the powers and constitution of matter

2235 Bodies having rotating power of themselves, do not seem by that to have a greater or a less tendency to assume a further degree of the same force under the influence of magnetic or electric power.

2236 Were it not for these and other differences, we might see an analogy between those bodies, which possess at all times the rotating power, as a specimen of quartz which rotates only in one plane, and also those to which the power is given by the induction of other forces, as a prism of heavy glass in a helix, on the one hand, and, on the other, a natural magnet and a helix through which the current is passing The natural condition of the magnet and quartz, *and the constrained condition of the helix and* heavy glass, form the link of the analogy in one direction, whilst the supposition of currents existing in the magnet and helix, and only a tendency or tension to currents existing in the quartz and heavy glass, supplies the link in the transverse direction

2237. As to those bodies which seem as yet to give no indication of the power over light, and therefore none of the assumption of the new magnetic conditions, these may be divided into two classes, the one including air, gases and vapours, and the other rock crystal, Iceland spar, and certain other crystalline bodies As regards the latter class, I shall give, in the next series of these researches, proofs drawn from phenomena of an entirely different kind, that they do acquire the new magnetic condi*tion; and these being so disposed of for the mo*ment, I am inclined to believe that even air and gases have the power to assume the peculiar state, and even to affect light, but in a degree so small that as yet it has not been made sensible Still the gaseous state is such a remarkable condition of matter, that we ought not too hastily to assume that the substances which, in the solid and liquid state, possess properties even general in character, always carry these into their gaseous condition

2238 Rock salt, fluor-spar, and, I think, alum, affect the ray of light, the other crystals experimented with did not, these are equiaxed and singly refracting, the others are unequi*axed and doubly refracting. Perhaps these in*stances, with that of the rotation of quartz, may even now indicate a relation between magnetism electricity, and the crystallizing forces of matter

2239 All bodies are affected by helices as by magnets, and according to laws which show that the causes of the action are identical as well as the effects This result supplies another fine proof in favour of the identity of helices and magnets, according to the views of Ampère

2240 The theory of static induction which I formerly ventured to set forth (1161, &c), and which depends upon the action of the contig uous particles of the dielectric intervening between the inductric and the inducteous bodies, led me to expect that the same kind of dependence upon the intervening particles would be found to exist in magnetic action, and I published certain experiments and considerations on this point seven years ago (1709-1736) I could not then discover any peculiar condition of the intervening substance or diamagnetic, but now that I have been able to make out such a state, which is not only a state of tension (2227), but dependent entirely upon the magnetic lines which pass through the substance, I am more than ever encouraged to believe that the view then advanced is correct

2241 Although the magnetic and electric forces appear to exert no power on *the ordinary* or on the depolarized ray of light, we can hardly doubt but that they have some special influence, which probably will soon be made apparent by experiment Neither can it be supposed otherwise than that the same kind of action should take place on the other forms of radiant agents as heat and chemical force

2242 This mode of magnetic and electric action, and the phenomena presented by it, will, I hope, greatly assist hereafter in the investigation of the nature of transparent bodies, of light, of magnets, and their action one on another or on magnetic substances I am at this time engaged in investigating the new magnetic condition, and shall shortly send a further account of it to the Royal Society What the possible effect of the force may be in the earth as a whole or in magnets, or in relation to the sun, and what may be the best means of

time and thought, aided by experiment, in the investigation and development of real truth, than to use them in the invention of suppositions which may or may not be founded on, or consistent with, fact

Royal Institution, Oct 29, 1845

TWENTIETH SERIES[1]

§ 27. *On New Magnetic Actions, and on the Magnetic Condition of All Matter*[2] ¶ i. *Apparatus Required* ¶ ii *Action of Magnets on Heavy Glass* ¶ iii. *Action of Magnets on Other Substances Acting Magnetically on Light* ¶ iv. *Action of Magnets on Metals Generally*

RECEIVED DECEMBER 6, READ DECEMBER 18, 1845

2243 THE contents of the last Series of these *Researches* were, I think, sufficient to justify

the phenomena of

tion of magnetic and electric forces (2227), which new condition was made manifest by the powers of action which the matter had acquired over light The phenomena now to be described are altogether different in their nature, and they prove, not only a magnetic con-

fundamental principles

2244 The whole matter is so new, and the

present state of our knowledge, such is the only method by which I can make these principles and their results sufficiently manifest

¶ i *Apparatus Required*

2245 The effects to be described require magnetic apparatus of great power, and under perfect command Both these points are obtained by the use of electro-magnets, which

can be raised to a degree of force far beyond that of natural or steel magnets, and further, can be suddenly altogether deprived of power, or made energetic to the highest degree, without the slightest alteration of the arrangement, or of any other circumstance belonging to an experiment

2246 One of the electro magnets which I use is that already described under the term Woolwich helix (2192) *The soft iron core belonging* to it is 28 inches in length and 2 5 inches in diameter When thrown into action by ten pair of Grove s plates either end will sustain one or two half hundred weights hanging to it The magnet can be placed either in the vertical or the horizontal position The iron core is a cylinder with flat ends, but I have had a cone of iron made, 2 inches in diameter at the base and 1 inch in height, and this placed at the end of the core, *forms a conical termination to it*, when required

2247 Another magnet which I have had made has the horseshoe form The bar of iron is 46 inches in length and 3 75 inches in diameter, and is so bent that the extremities forming the poles are 6 inches from each other, 522 feet of copper wire 0 17 of an inch in diameter, and covered with tape, are wound round the two straight parts of the bar, forming two coils on these parts, each 16 inches in length, and composed of three layers of wire the poles are, of course, 6 inches apart, the ends are planed true, and against these move two short bars of soft iron, 7 inches long and 2½ by 1 inch thick, which can be adjusted by screws, and held at any distance less than 6 inches from each other The ends of these bars form the opposite poles of contrary name, the magnetic field between them can be made of greater or smaller extent and the intensity of the lines of magnetic force be proportionately varied

2248 For the suspension of substances between *and near the poles of these magnets*, I occasionally used a glass jar, with a plate and sliding wire at the top Six or eight lengths of cocoon silk being equally stretched, were made into one thread and attached, at the upper end, to the sliding rod, and at the lower end to a stirrup of paper, in which anything to be experimented on could be sustained

2249 Another very useful mode of suspension was to attach one end of a fine thread, 6 feet long, to an adjustable arm near the ceiling of the room, and terminating at the lower end by a little ring of copper wire, any substance to be suspended could be held in a simple cradle of fine copper wire having 8 or 10 inches of the wire prolonged upward, this being bent into a hook at the superior extremity, gave the means of attachment to the ring The height of the suspended substance could be varied at pleasure, by bending any part of the wire at the instant into the hook form A glass cylinder placed between the magnetic poles was quite sufficient to keep the suspended substance free *from any motion, due to the agitation of the air*

2250 It is necessary, before entering upon an experimental investigation with such an apparatus, to be aware of the effect of any magnetism which the bodies used may possess, the power of the apparatus to make manifest such magnetism is so great, that it is difficult on that account to find writing-paper fit for the stirrup above mentioned Before therefore any experiments are instituted, it must be ascertained *that the suspending apparatus employ*ed does not point, i e, does not take up a position parallel to the lines joining the magnetic poles, *by virtue of the magnetic force* When copper suspensions are employed, a peculiar effect is produced (2309), but when understood, as it will be hereafter, it does not interfere with the results of experiment The wire should be fine, not magnetic as iron, and the form of the suspending cradle should not be elongated horizontally, but be round or square as to its general dimensions, in that direction

2251 The substances to be experimented with should be carefully examined, and rejected if not found free from magnetism Their state is easily ascertained, for, if magnetic, they will either be attracted to the one or the other pole of the great magnet, or else point between them No examination by smaller magnets, or by a magnetic needle, is sufficient for this purpose

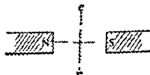


Fig 1

2252 I shall have such frequent occasion to refer to two chief directions of *position* across the magnetic field, that to avoid periphrasis, I will here ask leave to use a term or two, conditionally One of these directions is that from pole to pole, or along the line of magnetic force, I will call it the *axial direction* the other is the direction perpendicular to this, and across the

line of magnetic force and for the time and as *respects the space between the poles I will call* it the *equatorial direction* Other terms that I may use, I hope will explain themselves

¶ ii *Action of Magnets on Heavy Glass*

2253 The bar of silicated borate of lead or

ed turning round its point of suspension into a position across the magnetic curve or line of force and after a few vibrations took up its place of rest there On being displaced by hand from this position it returned to it and this occurred many times in succession

2254 Either end of the bar indifferently went to either side of the axial line The determining circumstance was simply inclination of the bar one way or the other to the axial line at the beginning of the experiment If a particular or marked end of the bar were on one side of the magnetic, or axial line when the magnet was rendered active that end went farther outwards until the bar had taken up the equatorial position

2255 Neither did any change in the magnetism of the poles by change in the direction of the electric current cause any difference in this respect The bar went by the shortest course to the equatorial position

2256 The power which urged the bar into this position was so thoroughly under command *that if the bar were swinging it could* easily be hastened in its course into this position or arrested as it was passing from it by

When in the direction of the axis or magnetic

(2298 2299 2384)

2258 Here then we have a magnetic bar which points east and west, in relation to north and south poles i e points perpendicularly to *the lines of magnetic force*

2259 If the bar be adjusted so that its point of suspension being in the axial line is not equidistant from the poles but near to one of

pleasure But at the same time there is another effect for at the moment of completing the electric contact the centre of gravity of the *bar recedes from the pole and remains repelled* from it as long as the magnet is retained excited On allowing the magnetism to pass away, the bar returns to the place due to it by its gravity

2260 Precisely the same effect takes place at the other pole of the magnet Either of them is able to repel the bar whatever its position may be and at the same time the bar is made to assume a position, at right angles to the line of magnetic force

2261 If the bar be equidistant from the two poles and in the axial line then no repulsive effect is or can be observed

2263 Instead of two magnetic poles a single pole may be used and that either in a vertical or a horizontal position The effects are in perfect accordance with those described above

tion makes the bar a tangent to the curve of its surface

2264 To produce these effects, of pointing *across the magnetic curves the form of the* heavy glass must be long a cube or a fragment approaching roundness in form will not point but a long piece will Two or three rounded pieces or cubes placed side by side in a paper tray, so as to form an oblong accumulation, will also point

2265. Portions, however, of any form, are *repelled* so if two pieces be hung up at once in the axial line, one near each pole, they are repelled by their respective poles, and approach, seeming to attract each other Or if two pieces be hung up in the equatorial line, *one on each* side of the axis, then they both recede from the axis, *seeming to repel each other*

2266 From the little that has been said, it is evident that the bar presents in its motion a complicated result of the force exerted by the magnetic power over the heavy glass, and that, when cubes or spheres are employed, a much simpler indication of the effect may be obtained Accordingly, when a cube was thus used with the two poles, the effect was repulsion or recession from either pole, and also recession from the magnetic axis on either side

2267 So, the indicating particle would move, either along the magnetic curves, or across them, and it would do this either in one direction or the other, the only constant point being, that its tendency was to move from stronger to weaker places of magnetic force

2268 This appeared much more simply in the case of a single magnetic pole, for then the tendency of the indicating cube or sphere was to move outwards, in the direction of the magnetic lines of force The appearance was remarkably like a case of weak electric repulsion

2269 The cause of the pointing of the bar, or any oblong arrangement of the heavy glass, is now evident. It is merely a result of the tendency of the particles to move outwards, or into the positions of weakest magnetic action The joint exertion of the action of all the particles brings the mass into the position, which, by experiment, is found to belong to it

2270 When *one or two magnetic poles are* active at once, the courses described by particles *of heavy glass free to move, form a set of* lines or curves, which I may have occasion *hereafter to refer to, and as I have called air,* glass, water, &c, diamagnetic (2149), so I will *distinguish these lines by the term diamagnetic curves,* both in relation to, and contradistinction from, the lines called magnetic curves

2271 When the bar of heavy glass is immersed in water, *alcohol, or ether, contained in* a vessel between the poles, all the preceding effects occur, *the bar points and the cube recedes* exactly in the same manner as in air

2272 The effects equally occur in vessels of wood, stone, earth, copper, lead, silver, or any of those substances which *belong to the dia*magnetic class (2149).

2273 I have obtained the same equatorial direction and motions of the heavy glass bar as those just described, but in a very feeble degree, *by the use of a good common steel horse*shoe magnet (2157) I have not obtained them *by the use of the helices (2191, 2192) without* the iron cores

*2274 Here therefore we have magnetic re*pulsion without polarity, i e, without reference *to a particular pole of the magnet,* for either pole will repel the substance, and both poles will repel it at once (2262) *The heavy* glass, though subject to magnetic action, cannot be considered as magnetic, in the usual acceptation of that term, or as iron, nickel, cobalt, and their compounds It presents to us, under these circumstances, a magnetic property new to our knowledge, and though the phenomena are very different in their nature and character to those presented by the action of the heavy glass on light (2152), still they appear to be dependent on, or connected with, the same condition of the glass as made it then effective, and therefore, with those phenomena, prove the reality of this new condition

¶ iii *Action of Magnets on Other Substances Acting Magnetically on Light*

2275 We may now pass from heavy glass to the examination of the other substances, which when under the power of magnetic or electric forces, are able to affect and rotate a polarized ray (2173), and may also easily extend the investigation to bodies which, from their irregularity *of form, imperfect transparency,* or actual opacity, could not be examined by a polarized ray, *for here we have no difficulty in the* application of the test to all such substances

2276 *The property of being thus* repelled and affected by magnetic poles was soon found *not to be peculiar to heavy glass.* Borate of lead, flint-glass, and crown glass set in the same *manner equatorially, and were repelled* when near to the poles though not to the same degree *as the heavy glass*

2277 Amongst substances which could not *be subjected to the examination by light,* phosphorus in the form of a cylinder presented the *phenomena very well, I think* as powerfully as heavy glass, if not more so A cylinder of sul*phur, and a long piece of thick* India rubber, neither being magnetic after the ordinary fashion, *were well directed and repelled*

2278 Crystalline bodies were equally obedient, *whether taken from the single* or double refracting class (2237) Prisms of quartz, cal-

careous spar, nitre and sulphate of soda, all pointed well, and were repelled

2279 I then proceeded to subject a great number of bodies, taken from every class, to the magnetic forces, and will, to illustrate the variety in the nature of the substances, give a com-

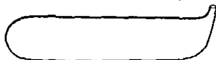


Fig 2

paratively short list of crystalline, amorphous, liquid and organic bodies below When the [illegible]

alone, afterwards, when it is filled with liquid and examined, the effect is such that there is no fear of mistaking that due to the glass for that of the fluid The tubes must not be closed with cork, sealing-wax, or any ordinary substance taken at random, for these are generally magnetic (2285) I have usually so shaped them in the making, and drawn them off at the neck, as to leave the aperture on one side, so that when filled with liquid they require no closing.

2280

Rock crystal	Water
Sulphate of lime	Alcohol
Sulphate of baryta	Ether
Sulphate of soda	Nitric acid
Sulphate of potassa	Sulphuric acid
Sulphate of magnesia	*Muriatic acid*
Alum	Solutions of various alkaline and earthy salts
Muriate of ammonia	
Chloride of lead	Glass
Chloride of sodium	Litharge
Nitrate of potassa	White arsenic
Nitrate of lead	Iodine
Carbonate of soda	Phosphorus
Iceland spar	Sulphur
Acetate of lead	Resin
Tartrate of potash and antimony	Spermaceti
	Caffeine
Tartrate of potash and soda	Cinchonia
	Margaric acid
Tartaric acid	Wax from shellac
Citric acid	Sealing wax
Olive oil	Mutton, dried
Oil of turpentine	Beef, fresh
Jet	Beef, dried
Caoutchouc	Blood, fresh
Sugar	Blood, dried
Starch	Leather
Gum-arabic	Apple
Wood	Bread
Ivory	

2281 It is curious to see such a list as this of bodies presenting on a sudden this remarkable property, and it is strange to find a piece of wood, or beef, or apple, obedient to or repelled by a magnet If a man could be suspended, with sufficient delicacy, after the manner of Dufay, and placed in the magnetic field, he would point equatorially, for all the substances of which he is formed, including the blood, possess this property

2282 The setting equatorially depends upon the form of the body, and the diversity of form presented by the different substances in the list was very great, still the general result, that elongation in one direction was sufficient to make them take up an equatorial position, was established It was not difficult to perceive that comparatively large masses would point [illegible]

dently appeared that the form of a plate or a ring was quite as good as that of a cylinder or a prism, and in practice it was found that plates and flat rings of wood, spermaceti, sulphur, &c, if suspended in the right direction, took up the equatorial position very well If a plate or ring of heavy glass could be floated in water, so as to be free to move in every direction, and were in that condition subject to magnetic [illegible]

a second operation, the calcareous spar was reduced into coarse particles, afterwards to a coarse powder, and ultimately to a fine pow- [illegible]

bodies in fine powder exhibited the effect very well

2284 It would require very nice experiments and great care to ascertain the specific degree of this power of magnetic action possessed by different bodies, and I have made very little progress in that part of the subject Heavy glass stands above flint-glass, and the latter above plate glass Water is beneath all these, and I think alcohol is below water, and ether below alcohol The borate of lead is I think as high as heavy glass, if not above it, and phosphorus is probably at the head of all the substances just named I verified the equatorial set of phosphorus between the poles of a common magnet (2273)

2285 I was much impressed by the fact that blood was not magnetic (2280), nor any of the specimens tried of red muscular fibre of beef or mutton This was the more striking, because as will be seen hereafter, iron is *always* and in almost *all states* magnetic But in respect to this point it may be observed, that the ordinary *magnetic property of matter and this new property* are in their effects opposed to each other, *and that when this property is strong it may* overcome a very slight degree of ordinary magnetic force, *just as also a certain amount of the* magnetic property may oppose and effectually hide the presence of this force (2422) It is this circumstance which makes it so necessary to be careful in examining the magnetic condition of the bodies in the first instance (2250) The following list of a few substances which were found slightly magnetic, will illustrate this point paper, sealing wax, china ink, Berlin porcelain, silkworm gut, asbestos, fluor-spar, red lead, vermilion, peroxide of lead, sulphate of zinc, tourmaline, plumbago, shellac, charcoal In some of these cases the magnetism was generally diffused through the body, in other cases it was limited to a particular part

2286 *Having arrived at this point, I may* observe, that we can now have no difficulty in *admitting that the phenomena abundantly es*tablish the existence of a magnetic property in matter, new to our knowledge *Not the least* interesting of the consequences that flow from it is the manner in which it disposes of the assertion which has sometimes been made, that all bodies are magnetic Those who hold this view, mean that all bodies are magnetic as iron is, and say that they point between the poles The new facts give not a mere negative to this statement, but something beyond, namely, an affirmative as to the existence of forces in all ordinary bodies, directly the opposite of those existing in magnetic bodies, for whereas those practically produce attraction, these produce repulsion, those set a body in the axial direction, but these make it take up an equatorial position and the facts, with regard to bodies generally, are exactly the reverse of those which the view quoted indicates

¶ iv *Action of Magnets on Metals Generally*

2287 *The metals, as a class, stand amongst* bodies having a high and distinct interest in re*lation both to magnetic and electric forces, and* might at first well be expected to present some peculiar phenomena, in relation to the striking property found to be possessed in common by so large a number of substances, so varied in their general characters As yet no distinction associated with conduction or non-conduction, transparent or opaque, solid or liquid, crystalline or amorphous whole or broken, has presented itself whether the metals, distinct as they are as a class would fall into the great *generalization, or whether at last a separation* would occur, was to me a point of the highest *interest*

2288 That the metals, iron, nickel and cobalt, *would stand in a distinct class, appeared* almost undoubted and it will be I think, for the advantage of the inquiry, that I should consider them in a section apart by themselves Further if any other metals appeared to be magnetic, as these are, it would be right and expedient to include them in the same class

2289 My first point, therefore, was to examine the metals for any indication of ordinary magnetism Such an examination cannot be carried on by magnets anything short in power of those to be used in the further investigation, and in proof of this point I found many specimens of the metals, which appeared to be perfectly free from magnetism when in the presence of *a magnetic needle, or a strong* horseshoe magnet (2157), that yet gave abundant *indications when suspended near to one or* both poles of the magnets described (2246)

2290 My test of magnetism *was this* If a bar of the metal to be examined, about 2 inches long, was suspended (2249) in *the magnetic* field, and being at first oblique to *the axial line* was upon the supervention of *the magnetic* forces drawn into the axial position instead of being driven into the equatorial line, *or re*maining in some oblique direction, then I considered it magnetic Or, if being near one magnetic pole, it was attracted by the pole, instead

of being repelled, then I concluded it was magnetic It is evident that the test is not strict, because, as before pointed out (2285), a body may have a slight degree of magnetic force, and yet the power of the new property be so great as to neutralize or surpass it In the first case, it might seem neither to have the one property nor the other, in the second case, it

that when examined as above, they did not appear to be magnetic, and in fact, if magnetic, were so to an amount so small as not to destroy the results of the other force, or to stop the progress of the inquiry.

Antimony	Lead
Bismuth	Mercury
Cadmium	Silver
Copper	Tin
Gold	*Zinc*

2292 The following metals were, and are as yet to me, magnetic, and therefore companions of iron, nickel and cobalt

Platinum
Palladium
Titanium

2293 Whether all these metals are magnetic, in consequence of the presence of a little iron, nickel, or cobalt in them, or whether any of them are really so of themselves, I do not undertake to decide at present, nor do I mean to say that the metals of the former list are free I have been much struck by the apparent free-

spect

to be carefully distinguished One of these depends upon induced magneto-electric currents, and shall be resumed hereafter (2309) The other includes effects of the same nature as those produced with heavy glass and many other bodies (2276)

2295 All the non-magnetic metals are subject to the magnetic power, and produce the

appears to be especially fitted for the purpose It excels heavy glass, or borate of lead, and perhaps phosphorus, and a small bar or cylinder of it about 2 inches long, and from 0 25 to 0 5 of an inch in width, is as well fitted to show the various peculiar phenomena as anything I have yet submitted to examination

2296 To speak accurately, the bismuth bar which I employed was 2 inches long, 0 33 of an inch wide, and 0 2 of an inch thick When this bar was suspended in the magnetic field, between the two poles, and subject to the magnetic force, it pointed freely in the equatorial direction, as the heavy glass did (2253), and if disturbed from that position, returned *freely* to it This latter point, though perfectly in accordance with the former phenomena, is in such striking contrast with the phenomena presented by copper and some other of the metals (2309), as to require particular notice here

2297. The comparative sensibility of bismuth causes several movements to take place under various circumstances, which being complicated in their nature, require careful analysis and explanation The chief of these, with their causes, I will proceed to point out

2298 If the cylinder electro-magnet (2246) be placed vertically so as to present one pole

of this face and close to it, does not move by

at present an upward direction from the core).

If carried a little farther outwards, the magnetism then makes the bismuth ball tend to go outwards or be repelled, and such continues to be the direction of the force in any further position, or down the side of the end of the

2299 In fact, the circular edge

the intersection of the end of the

sides, is virtually the apex of the magnetic pole, to a body placed like the bismuth ball close to it, and it is because the lines of magnetic force issuing from it diverge as it were, and weaken *rapidly in all directions from it*, that the ball also tends to pass in all directions either inwards or upwards, or outwards from it, and thus produces the motions described *These same effects do not in fact all occur* when the ball being taken to a greater distance from the iron, is placed in magnetic curves having generally a simpler direction *In order to remove the effect of the edge, an* iron cone was placed on the top of the core, converting the flat end into a cone and then the indicating ball was urged to move upwards, *only when over the apex of the cone and up*wards and outwards, as it was more or less on one side of it, being always repelled from the pole in that direction, which transferred it *most rapidly from strong to weaker points of* magnetic force

2300 To return to the vertical flat pole when a horizontal bar of bismuth was suspended *concentrically and close to the pole it could* take up a position in any direction relative to the axis of the pole having at the same time a tendency to move upwards or be repelled from it *If its point of suspension was a little eccen*tric, the bar gradually turned until it was parallel to a line joining its point of suspension with the prolonged axis of the pole, and *the centre of gravity moved inwards* When its point of suspension was just outside the edge of the flat circular terminating face and the bar *formed a certain angle with a radial line* joining the axis of the core and the point of suspension, then the movements of the bar were uncertain and wavering If the angle with *the radial line were less than that above*, the bar would move into parallelism with the radius and go inwards if the angle were greater, the bar would move until perpendicular to the *radial line and go outwards If the centre* of the bar were still farther out than in the last case, or down by the side of the core, the bar would *always place itself perpendicular to the radius and go outwards* All these complications of motion are easily resolved into their simple elementary origin, if reference be had to the character of the circular angle bounding the end of the core, to the direction of the magnetic lines of force issuing from it and the other parts of the pole to the position *of the different parts of the bar in these lines*, and the ruling principle that each particle tends *to go by the nearest course from strong to weaker* points of magnetic force

2301 The bismuth points well, and is well repelled (2296) when immersed in water, alcohol, ether, oil, mercury, &c, and also when enclosed within vessels of earth, glass, copper, lead &c (2272), or when screens of 0 75 or 1 inch in thickness of bismuth, copper, or lead *intervene* Even when a *bismuth cube (2266)* was placed in an iron vessel 2½ inches in diameter and 0 17 of an inch in thickness it was well and freely repelled by the magnetic pole

2302 Whether the bismuth be in one piece or in very fine powder, appears to make no difference in the character or in the degree of its *magnetic property (2283)*

2303 I made many experiments with masses and bars of bismuth suspended, or otherwise circumstanced, to ascertain whether two pieces *had any mutual action on each other, either of* attraction or repulsion, whilst jointly under the influence of the magnetic forces, but I could not find any indication of such mutual action *they appeared to be perfectly indifferent one* to another each tending only to go from stronger to weaker points of magnetic power

2304 Bismuth, in very fine powder, was *sprinkled upon paper, laid over the horizontal* circular termination of the vertical pole (2246) If the paper were tapped the magnet not being excited, nothing particular occurred *but if* the magnetic power *were on*, then the powder retreated in both directions, inwards and outwards, from a circular line just over the edge of *the core, leaving the circle clear* and *at the* same time showing the tendency of the particles of bismuth in all directions from that line (2299)

2305 *When the pole was terminated* by a cone (2246) and the magnet not in action paper with bismuth powder sprinkled over it being drawn over the point of the cone, gave *no particular result, but when the magnetism was* on, such an operation cleared the powder from every point which came over the cone, so that a mark was traced or written out in *clear lines* running through the powder, and showing every place where the pole had passed

2306 The bar of bismuth and a bar of *antimony was found to set equatorially* between the poles of the ordinary horseshoe magnet

2307 The following list may serve to give an idea of the apparent order of some *metals, as* regards their power of producing these new effects, but I cannot be sure that they are per-

fectly free from the magnetic metals In addition to that, there are certain other effects produced by the action of magnetism on metals (2309) which greatly interfere with the results due to the present property

Bismuth	Cadmium
Antimony	Mercury
Zinc	Silver
Tin	Copper

was the consequence of a general property, which is now shown to belong to all matter [1]

2309 I now turn to the consideration of some peculiar phenomena which are presented by *copper and several of the metals when they are subjected to the action of magnetic forces,* and which so tend to mask effects of the kind already described that if not known to the inquirer they would lead to much confusion and doubt These I will first describe as to their appearances, and then proceed to consider their origin

to the axial and equatorial lines the experimenter will perceive the bar to be affected but this will not be manifest by any tendency of

rations This effect is in striking contrast with that which occurs when antimony, bismuth, heavy glass, or other such bodies are employed, and it is equally removed from an ordinary magnetic effect

2311 The position which the bar has taken up it retains with a considerable degree of tenacity, provided the magnetic force be continued If pushed out of it, it does not return into it, but takes up its new position in the same manner, and holds it with the same stiffness, a push, however, which would make the bar spin round several times if no magnetism were present, will now not move it through more than 20° or 30° This is not the case with bismuth or heavy glass they vibrate freely in the magnetic field, and always return to the equatorial position

2312 The position taken up by the bar may be *any position The bar is moved a little at*

bar may be placed at the beginning of the ex-

2314 If the centre of suspension of the bar

2315 Having thus stated the effect of the

ally to move through two or

2316 Heavy glass or bismuth present no such phenomena as this

2317 If, whilst the bar is revolving from revulsion the electric current at the magnet be renewed, the bar instantly stops with the former appearances *and results (2310), and then* upon removing the magnetic force is affected again, and, of course now in a contrary direction *to the former revulsion*

2318 When the bar is caught by the magnetic force in the axial or equatorial position, *there is no revulsion When inclined to these* positions, there is and the places most powerful in this respect appear to be those most *favourable to the first brief advance (2313) If* the bar be in a position at which strong revulsion would occur and whilst the magnetism is continued be moved by hand into the equatorial or axial position then on taking off the magnetic force there is no revulsion

2319 If the continuance of the electric current and consequently of the magnetism be for a moment only, *the revulsion is very little*, and the shorter the continuance of the magnetic force the less is the revulsion If the magnetic *force be continued for two or three seconds and* then interrupted and *instantly* renewed, the bar is loosened and caught again by the power *before it sensibly changes its place and now it* may be observed that it does not advance on the *renewal* of the force as it would have done had *it been acted on by a first contact in that* place (2310), i.e , if the bar be in a certain place inclined to the axial position, the first supervention of the magnetic power causes it to advance towards the axial position, but the bar being in the same place and the magnetic power suspended and *instantly* renewed, the second supervention of force does not move the bar as the first did

2320 When the copper bar is immersed in water, alcohol, or even mercury, the same *effects take place as in the air, but the move*ments are, of course, not to the same extent

2321 When plates of copper or bismuth, an inch in thickness, intervene between the poles and the copper bar, the same results occur

2322 If one magnetic pole only be employed the effects occur near it as well as before, provided that pole have a face large in proportion to the bar, as the end *of the iron core (2246) but* if the pole be pointed by the use of the conical termination, or if the bar be opposite the edge of the end *of the core, then they become great*ly enfeebled or disappear altogether, and only the general fact of repulsion remains (2295).

2323 The peculiar effects which have just been described are perhaps more strikingly shown if the bar of copper be suspended perpendicularly, and then hung opposite and near to the large face of a single magnetic pole, or the pole being placed *vertically*, as *described* (2246, 2263), anywhere near to its side The bar, it will be remembered, is 2 inches in length *by 0 33 of an inch in width, and 0 2 of an inch* in thickness, and as it now will revolve on an axis parallel to its length, the two smaller *dimensions are those which are free to move into* new positions In this case the establishment of the magnetic force causes the bar to turn a little *in accordance with the effects before described* and the removal of the magnetic force causes a revulsion, which sends the bar spinning round *on its axis several times* But at any moment the bar can again be caught and held in a position as before The tendency on making contact at the battery is to place the longest moving dimension, i e , the width of the bar *parallel to the line joining the centre of action of* the magnet and the bar

2324 The bar, as before (2311), is extremely *sluggish and as if immersed in a dense fluid* as respects rotation on its own axis, but this sluggishness does not affect the bar as a whole for *any pendulum vibration it has, continues un*affected It is very curious to see the bar, jointly vibrating from its point of suspension (2249) *and rotating on its axis, when first affected by* the magnetic force, for instantly the latter motion ceases, but the former goes on with undiminished power

2325 The same effect of sluggishness occurs with a cube or a globe of copper as with the bar, but the phenomena of the first turn and the revulsion cease (2310, 2315)

2326 The bars of bismuth and heavy glass present no appearance of this kind The peculiar phenomena produced by copper are as *distinct from the actions of these* substances as they are from ordinary magnetic actions

2327 Endeavouring to explain the *cause of* these effects, it appears to me that they depend upon the excellent conducting power of copper *for electric currents, the gradual* acquisition and loss of magnetic power by the iron core of the electro-magnet, and the production *of those induced currents of magneto-electricity* which I described in the first series of these *Experimental Researches* (55, 109)

2328 The obstruction to motion on its own axis, when the bar is subjected to the magnetic forces, belongs equally to *the form of* a sphere

or a cube It belongs to these bodies, however, only when their axes of rotation are perpendicular or oblique to the lines of magnetic force, and not when they are parallel to it for the horizontal bar, or the vertical bar, or the cube or sphere, rotate with perfect facility when they are suspended *above* the vertical pole (2246),

tion is at a maximum when the axis of rotation is perpendicular to the lines of magnetic force, and when the bar or cube, &c, is near to the magnet

2329 Without going much into the particular circumstances I may say that the effect is fully explained by the electric currents induced

of magnetic force is revolving on an axis perpendicular to these lines an electric current runs round it in a plane parallel to the axis of

ducing magnet The magnetic poles of this axis therefore are in that direction which in con

state Whichever way therefore the copper

magnetic lines of force and con equently i a tendency to the formation of magneto-electric currents within it yet as all parts mo

with equal velocity and in the same direction through similar magnetic lines of force, the tendency to the formation of a current is the same in every part, and there is no actual production of current, and consequently nothing occurs which can in any way interfere with its freedom of motion Hence the reason that though *the rotation of the bar or cube* (2324 2328) upon its own axis is stopped its vibration as a pendulum is not affected

2331 That neither the one nor the other motion is affected when the bar or cube is over the vertical pole (2328) is simply because in both

return of the current can be carried on no current can be formed

2332 Before proceeding to the explanation of the other phenomena it will be necessary to point out the fact generally understood and acknowledged, I believe that *time* is required for the development of magnetism in an iron core by a current of electricity and also for its fall back again when the current is stopped One

are due) also appear to be lost more slowly than the other portions of the power If electric contact be made for an instant only, the magnetism developed by the current disappears as instantly on the breaking of the current as it

rapidly

2333 In order to trace the peculiar effect of the copper, and its cause, let us consider the condition of the horizontal bar (2310, 2313) when in the equatorial position between the two magnetic poles or before a single pole, the

[1] *Philosophical Transactions* 1832 p 163.

bar in the contrary direction This is shown

and carrying away the currents produced in it, by wires to a galvanometer at a distance

they continue, they give a virtual magnetic polarity to that face of the copper bar which is opposite to a certain pole, the polarity being the same in kind as the pole it faces Thus on

2334 It is easy to see that if the copper during this time were opposite only one pole or being between two poles were nearer to one

them They do however, cause a brief repulsive effort, to which is chiefly due the first part of the peculiar effect

stance an angle of 45° with the face then the induced currents will move generally in a plane

other magnetic pole upon the two polarities of the copper will be to send it farther round, or to place it edgeways to the poles or with its breadth parallel to the magnetic resultant

action before described (2330) At the same time that this twist or small portion of a turn round the point of suspension occurs, the centre of gravity of the whole mass is repelled, and thus I believe all the actions up to this condition of things are accounted for

2336 Then comes the *revulsion* which occurs upon the cessation of the electric current, and the falling of the magnetism in the core According to the law of magneto-electric induc

in the first instance, and therefore the virtual magnetic pole belonging to the copper for the moment, which is nearest the north end of the electro magnet will be a south pole and that which is farthest from the same pole of the *magnet will be a north pole Hence will arise* an exertion of force on the bar tending to turn it round its centre of suspension in the con trary direction to that which occurred before,

net and an action the reverse in every respect of the first action will take place, except that whereas the motion was then only a few de grees now it may extend to two or three revolutions

2337 The cause of this difference is very ob-

case these influences are gone and the bar revolves freely with a force proportionate to the power exerted by the magnet upon the cur rents induced by its own action

2338 Even when the copper is of such form as not to give the oblique resultant of magnetic action from the currents induced in it when, for instance it is a cube or a sphere still the effect of the action described above is evident (2325) When a plate of copper about three-fourths of an inch in thickness, and weighing two pounds, was sustained upon some loose

making and continuing of electric contact at

tion towards the magnet, so that it gave a strong tap against it

2339 Such is I believe the explanation of the peculiar phenomena presented by copper in the magnetic field and the reason why they appear with this metal and not with bismuth or heavy glass is almost certainly to be found in its high electro-conducting power which permits the formation of currents in it by inductive forces that cannot produce the same in a

by virtue of their inherent power or the presence of small portions of the magnetic metals in them must oppose the development of the results I have been describing and hence metals not of absolute purity cannot be compared with each other in this respect I have never

er degree

Copper	Mercury
Silver	Platinum
Gold	Palladium
Zinc	Lead
Cadmium	Antimony
Tin	Bismuth

2341 The accordance of these phenomena with the beautiful discovery of Arago [1] with the results of the experiments of Herschel and

much as the circumstances of the experiment and the energy of the apparatus are not sufficiently stated but it probably may have been

2342 As because of other duties three or four weeks may elapse before I shall be able to complete the verification of certain experi

searches

Royal Institution Nov 27, 1845

nets

[?] *Philosophical Transactions* 1825 p 467

[?] *Ibid* 1832 p 146

Bibliothèque Universelle XXI p 48

TWENTY-FIRST SERIES[5]

§ 27 *On New Magnetic Actions and on the Magnetic Condition of All Matter (continued)* ¶ v *Action of Magnets on the Magnetic Metals and Their Compounds* ¶ vi *Action of Magnets on Air and Gases* ¶ vii *General Considerations*

Received December 24 1845 Read January 8 1846

¶ v *Action of Magnets on the Magnetic Metals and Their Compounds*

inactive when hot on common magnets or to common tests they are not so absolutely, but retain a certain amount of magnetic power

whatever their temperature and also that this power is the same in character with that which they ordinarily possess

[5] *Philosophical Transactions* 1846 p

ment of the flame, and the electro-magnet thrown into action Immediately the hot iron became magnetic and pointed between the poles The power was feeble, and in this respect the state of the iron was in striking contrast with that which it had when cold, but in character the force was precisely the same

2345 The iron was then allowed to fall in temperature slowly so that its assumption of the higher magnetic condition might be observed The intensity of the force did not appear to increase until the temperature arrived near a certain point, and then as the heat continued to diminish, the iron rapidly, but not instantaneously, acquired its high magnetic power, at which time it could not be kept from the magnet, but flew to it, bending the suspending wire and trembling as it were with magnetic energy as it adhered by one end to the core

2346 A small bar of nickel was submitted to an experimental examination in the same manner This metal, as I have shown,[1] loses its magnetism as respects ordinary tests at a heat below that of boiling oil and hence it is very well fitted to show whether the magnetic metals can have their power entirely removed by heat

termination of the latter point Upon being heated the nickel soon became indifferent to ordinary magnets but however high the temperature, still it pointed to and was attracted by the electro-magnet The power was very

when the metal was supported as described (2344)

2347 On carefully lowering the temperature of the nickel, it was again found that the transition from one degree of magnetic force to the other was progressive and not instantaneous With iron it is difficult to preserve all the parts, either in heating or cooling, so nearly at the same temperature as to be sure that it is not time before the full degree of power came on, at any time in that period the temperature might be slightly raised, and though the power would then diminish a little, it could yet be retained at a degree stronger than the weakest In fact it was easy to *keep* the nickel at many of the intermediate degrees of power, and thus to remove all doubt of the progressive assumption of the full degree of force

2348 I have expressed an opinion, founded on the different temperatures at which the magnetic metals appeared to lose their peculiar power,[2] that all the metals would probably have the same character of magnetism if their temperature could be lowered sufficiently The facts just described appear to me entirely against such an opinion The metals which are magnetic retain a portion of their power after

present no trace of this power, and therefore

to withdraw the view I then put forth

2349 I next proceeded to examine the peroxides of iron, and in accordance with the observations of M Becquerel[3] and others found them all, both natural and artificial, possessed of magnetic power at common temperatures I heated them in tubes but found them still magnetic, suffering *no* diminution of the *force* by such temperature as I could apply to them

2350 Different specimens of the oxide of nickel were found to present the same phenomena They were magnetic both when hot and cold, and that heat should cause no change in this respect is the more striking, because the hot oxide had a temperature given to it far higher than that necessary to produce the great magnetic change in the metal itself (2346)

2351 The oxide of cobalt also was magnetic, and equally magnetic whether hot or cold Glass coloured blue by cobalt is magnetic in consequence of the presence of the oxide of that metal, and is so whether hot or cold In all these cases the degree of power retained was very small compared to that of the pure metal

2352 Proceeding to the *salts* of iron, I found them magnetic Clean crystals of the proto-

[1] *Philosophical Magazine* 1836 Vol VIII p 179 or *Experimental Researches* Vol II p 219

[2] *Philosophical Magazine* 1836 Vol VIII p 177 *ibid* 1839 Vol XIV p 161 or *Experimental Researches* Vol II pp 217 225

[3] *Annales de Chimie* 1827, Vol XXXVI, p 337 *Comptes Rendus* 1845 Vol XX, p 1708

sulphate of iron were attracted and pointed axially very well so also d d the dry salt As I proceeded I found that every salt and com pound contain ng iron in the bas c part was magnetic To enumerate the different sub stances subjected to trial would be tedious the following are selected as illustrations of the variety in kind

Protochloride	Protophosphate
Perchloride	Perphosphate
Iodide	Nitrate
Protosulphate	Carbonate
Persulphate	Pruss an Blue

2353 Amongst native compounds

Bog iron ore	Yellow sulphuret of iron
Hæmatite	Arsenical pyrites
Chromate of iron	Copper pyrites and many others were magnet c

2354 Green bottle-glass is comparatively very magnet c from the iron it contains and cannot be used as tubes to hold other substances Crown glass is magnetic from the same cause Flint glass is not magnetic but po nts equatorially

2355 Crystals of the yellow ferro-prussiate of potassa[1] were not magnetic but were repelled and set equatorially and such was the case also with red ferro-pruss ate

or proto- or perchloride or t ncture of muriate of iron was attracted by the poles and pointed very well between them in the axial direction

2357 These solut ons supply a very impor tant means of advanc ng magnetical investiga t on for they present us with the po ver of mak ng a magnet wh ch is at the same time

magnets examined as to their jo nt or separate actions in it (2361 &c)

2358 In reference to the salts of *nickel* and *cobalt* pure crystals of the sulphate of nickel were found to be well magnetic and also pure

1 Ferro-prussiate of potassa now known as potassium ferricyanide.—Ed.

also tl e scale upon which he carries on these operations and he favoured me with a solution of chloride of nickel and another of chloride of

2360 Tl ese results with the salts of the mag netic metals conjoin with tl ose before quoted

d stinct from iron nickel and cobalt for none of tl e compounds of the non magnet c metals show as yet any indicat on of or linary mag netic force wl ereas in respect of these three

field

2362 A clear solution of the proto-sulphate of iron was prepared in which one ounce of the l quid contained seventy four grains of the hy drated crystals a second solut on was prepared

dist ngu.h as Nos 1 2 and 3 the proportions of crystals of sulphate of iron in them were respectively as 16 4 an l 1 per cent nearly These

solutions were also prepared large enough to allow the tubes to move free them and yet of such size and shape as mit of their being placed between t ales. In this manner the action

forces upon the matter in the tubes could be examined and observed, both when the tubes were in diamagnetic media, as air, water, alcohol, &c, and also in magnetic media, either stronger or weaker in magnetic force, than the substances in the tubes

2364 When these tubes were suspended in air between the poles, they all pointed axially or magnetically, as was to be expected, and with forces apparently proportionate to the strengths of the solutions When they were immersed in alcohol or water, they also pointed in the same direction, the strongest solution very well, and also the second, but the weakest solution was feeble in its action, though very distinct in its character (2422)

2365 When the tubes, immersed in the dif-

2366 The tube No 2, when in the solution

and not at all in solution No 3

2367 Several other ferruginous solutions varying in strength were prepared, and, as a general and constant result, it was found that any tube pointed axially if the solution in it was stronger than the surrounding solution, and equatorially if the tube solution was the weaker of the two

2368. The tubes were now suspended vertically, so that being in the different solutions they could be brought near to one of the magnetic poles, and employed in place of the indicating cube or sphere of bismuth, or heavy glass (2266) The constant result was that when the tube contained a stronger solution than that which surrounded it, it was attracted to

netic body in air

2369 Having described these phenomena, I will defer their further consideration until I arrive at the last division of this paper, and proceed to certain results more especially belonging to the present part of these *Researches*

2370 As the magnetic metals, iron, nickel and cobalt, present in their compounds substances also distinguished by the possession of magnetic properties (2360), so it appeared very probable that other metals, of whose magnetic character doubts were entertained, because of the possible presence of iron in the specimens experimented with, might in this way have

the following results

2371 *Titanium* Wollaston has described the magnetic effects of crystals of titanium, expressing at the same time a belief that they are due to iron[1] I took a specimen of the oxide of titanium, which I believe to be perfectly free from iron, and inclosing it in a tube (2279), subjected it to the action of the electro-magnet (2246, 2247) It proved to be freely magnetic Another specimen obtained from Mr Johnson, and believed by him to be perfectly free from iron, was also magnetic Hence I conclude that titanium is truly a magnetic metal

2372 *Manganese* Berthier, as far as I am aware, first announced that this metal was magnetic at very low temperatures[2] On submitting specimens of the various oxides, which were considered as pure, to the magnetic force, they were all found to be magnetic, especially the protoxide So were the following compounds of manganese in the pure, dry, or crystallized state chloride, sulphate, ammonio-sulphate, phosphate, carbonate, borate, and also the

addition of a little carbonate of ammonia boiled and then carefully crystallized thrice after that the crystals and solution of the purified salt were perfectly and well magnetic I have no doubt, therefore, that manganese is a mag

[1] *Philosophical Transactions* 1823 p 400

[2] *Traité des Essais par la Voie Sèche* Vol I p 532. *Philosophical Magazine* 1845 Vol XXVII p 2

netic metal, as Berthier said If any opinion

phate of the oxide and potassa prepared with great care, I found them all magnetic, and those that are soluble are magnetic in the state of solution Hence, as the compounds are undoubtedly magnetic there is every reason to believe that cerium also is a magnetic metal (2370)

2374 *Chromium* The magnetic phenomena of chromium compounds are very interesting Portions of the chromate and the bichromate of potassa were purified by three careful crystallizations each, part of the bichromate was heated in a platinum crucible, until the second

chromium which were examined

A specimen of Warrington's chromic acid was found to be very feebly magnetic

2375 Chromate of lead when subjected to the magnet, pointed equatorially and was repelled Such was the case also with crystals of the chromate of potassa Crystals of the bichromate, however did not act thus for if in any way affected they were in the least degree magnetic, showing the influence of the increased proportion of chromic acid Solutions of either salt pointed well equatorially and were repelled, thus showing the diamagnetic influence of the water present (2422)

2376 As just stated, a solution of the bichromate contained in a tube, pointed equatorially and was repelled, but if the same solution had a little alcohol added to it, and also some pure muriatic or sulphuric acid, and were then heated for a few minutes to reduce the chromic acid to the state of oxide or chloride, then, on being returned to the tube and subjected to the magnet, it was found strongly magnetic

2377 I think it has before been said that chromium is a magnetic metal, as these results have been obtained with its pure compounds

[1] *Philosophical Magazine* 1845 Vol XXVII p 2

there is no longer any doubt in my mind that such is the case

2378 *Lead* The compounds of lead point equatorially and are repelled The substances tried were the chloride, iodide, sulphuret, ni-

move subsalts Such lead was free from magnetism, and therefore the metal ranks in the diamagnetic class, both directly and by its compounds Lead usually appears to be magnetic, and it is not very easy to obtain the metal in the pure diamagnetic state

2379 *Platinum* I have as yet, found no wrought specimens of this metal free from magnetism, not even those prepared by Dr Wollaston himself and left with the Royal Society Specimens of the purest platinum obtained from Mr Johnson were also found to be slightly magnetic

2380 Clean platinum foil and cuttings were dissolved in pure nitro-muriatic acid, and the solution evaporated to dryness Both the solution and the dry chloride pointed equatorially and were repelled by the magnet A part of the chloride, being dissolved and rendered acid, was precipitated by an acid solution of muriate of ammonia, and the ammonio-chloride of platinum washed and dried it also, at the magnet, pointed equatorially and was repelled A portion of this ammonio-chloride, decomposed in a flint-glass tube by heat, gave spongy platinum which being pressed together into a cake, pointed *axially* and was attracted at the side of the magnetic pole being magnetic

2381 At present I believe that platinum is as a metal magnetic, though very slightly so, and that in the compounds, the change of state and the presence of other substances having the diamagnetic character, are sufficient to cover this property and make the whole compound diamagnetic (2422)

2382 *Palladium* All the palladium in the

glass tubes, gave palladium feebl

degree of magnetic property Some of Wollaston's palladium was dissolved in pure nitromuriatic acid, and the solution slowly acted upon by pure zinc, free from iron, and not magnetic Five successive portions of the precipitated metal were collected, and *all* were *magnetic* Ammonio bichloride of palladium was prepared from the same solution by pure acid muriate of ammonia, and digested in nitromuriatic acid The salt itself was repelled, being diamagnetic, but when reduced by heat in glass tubes, or in Berlin capsules, the palladium obtained was magnetic From the result of all the experiments, I believe the metal to be

sublimed twice or thrice in succession, pre-

series of substances, being only in a very small degree removed from the zero or medium point Pure white arsenic points freely in an equatorial direction, and is repelled by a magnetic pole

2384 In reference to the pointing of short bars between magnetic poles exposing large flat faces, I ought to observe, that such bars will sometimes point axially and seem to be magnetic when they do not belong to that class, and are repelled by a single pole The cause of this effect has been already given (2298, 2299), and is obviated by the use of poles having wedge shaped or conical terminations

2385 *Osmium* Osmic acid from Mr Johnson, in fine transparent crystals, was clearly

from other substances Probably, therefore, osmium belongs to the magnetic class

netic, but crystals of the chloride and the sodio-chloride of rhodium prepared by the same philosopher, and others also from Mr Johnson, were not magnetic, but pointed well equatorially I conclude, therefore, that the metal is probably not magnetic, or if magnetic, is but little removed from the zero point

2388 *Uranium* Peroxide of this metal was

a diamagnetic metal

2390 *Silver* is not magnetic (2291), nor its compounds

2391 *Antimony* is not magnetic (2291), nor its compounds

2392 *Bismuth* is not magnetic (2291), nor its compounds

2393 *Sodium* A fine large globule, equal to half a cubic inch in size, was well repelled, and is therefore diamagnetic

2394 *Magnesium* None of the compounds or salts of this base is magnetic

2395

Calcium	Sodium
Strontium	Potassium
Barium	Ammonia

None of the compounds or salts of these sub-

the case with tungsten, uranium, rhodium &c

2397 I have heated several of the diamagnetic metals, even up to their fusing points, but have not been able to observe any change, either in the character or degree of their magnetic relations

2398 Perhaps the cooling of some of the metals, whose compounds like those of iron, nickel and cobalt, are magnetic might develop in them a much higher degree of force than any which they have as yet been known to possess Manganese chromium cerium titanium, are metals of much interest in this point of view Osmium, iridium, rhodium and uranium ought to be subjected with them to the same trial

2399 The following is an attempt to arrange some of the metals in order, as respects their

space The farther substances are placed from this point the more distinctive are they as regards their attraction or repulsion by the magnet Nevertheless this order may, very probably, be found inaccurate by more careful observation

Magnetic	Diamagnetic
	Bismuth
	Antimony
	Zinc
	Tin
	Cadmium
	Sodium
Iron	Mercury
Nickel	Lead
Cobalt	Silver
Manganese	Copper
Chromium	Gold
Cerium	Arsenic
Titanium	Uranium
Palladium	Rhodium
Platinum	Iridium
Osmium	Tungsten
0°	

¶ vi *Action of Magnets on Air and Gases*

2400 It was impossible to advance in an experimental investigation of the kind now described, without having the mind impressed with various theoretical views of the mode of

periments upon its probable influence, which I will now proceed briefly to describe

2401 A thin flint-glass tube in which common air was hermetically enclosed, was placed between the magnetic poles (2249) surrounded by air, and the effect of the magnetic force observed upon it There was a very feeble tendency of the tube to an equatorial position due to the substance of the tube in which the air was enclosed

2402 The air was then withdrawn from

2403 I then surrounded the air tube with hydrogen and carbonic acid in succession but in both these and in each of them at different degrees of rarefaction the tube of air remained as indifferent as before

2404 Hence there appears to be no sensible distinction between dense or rare air, or as far as these experiments go between one gas or vapour and another

2405 As it did not seem at all unlikely that the equatorial and axial set of bodies or their repulsions and attractions might depend upon converse actions of the media by which they were surrounded (2361), so I proceeded to examine what would occur with diamagnetic substances when the air or gas which surrounded them was changed in its density or nature or what would happen to air itself when surrounded by these substances

2406 The air tube (2401) was suspended horizontally in water (being retained below the surface by a cube of bismuth attached to it, just beneath the point of suspension which therefore could have no power of giving it direction), it was then subjected to the magnetic forces and immediately pointed well in an axial direction or as a magnet would have done Being brought near to one pole, it moved on

jected to the action of the magnetic force, when surrounded by alcohol and also by oil of turpentine with precisely the same results as in water In all these cases the action of air in the fluids was precisely the same as the action of a magnetic body in air The air tube was subjected to the action of the magnet even when under the surface of mercury, and here also it pointed axially

2408 In order to extend the experimental relations of air and gases I proceeded to place substances of the diamagnetic class in them. Thus the bar of heavy glass (2253) was sus-

pended in a jar of air and then the air about it more or less rarefied but as before in the case of the air tube (2402) alterations of this kind produced no effect Whether the bar were in air at the ordinary pressure or as rare as the pump could render it it still pointed equatorially and apparently always with the same degree of force

2409 The bar of bismuth (2296) was suspended in the jar and the same alteration in the density of the air made as before but this caused no difference in the action of the bismuth either in kind or degree Carbonic acid and hydrogen gases were then introduced in succession into the jar and these also were employed in different degrees of rarefaction but the results were the same no change took place in the action on the bismuth

2410 A bismuth cube was suspended in air and gases at ordinary pressure and also rarefied as much as could be and under these circumstances it was brought near the magnetic pole and its repulsion observed its action was in all these cases precisely the same as in the atmosphere

2411 The perpendicular copper bar (2323) was suspended near the magnetic pole *in vacuo*, but its set sluggish movements and revulsion were just the same as before in air (2324)

2412 The following preparations in tubes

same effect occurred

2413 The same preparations being surrounded by air or by carbonic acid gas all set equatorially

2414 The axial position of the tubes in the liquid (2412) depends doubtless upon the relation of the contents of the tube to the surrounding medium for as far as the matter of the tube is concerned it alone would have

all the variations of the gases and vapours is a proof how like and how indifferent these are one to the other

2415 I *suspended a tube of liquid sulphurous* acid in gaseous sulphurous acid, when under the magnetic influence the liquid pointed well equatorially I surrounded liquid nitrous acid by gaseous nitrous acid the liquid pointed well equatorially I placed liquid ether in the vapour of ether the former pointed equatorially Upon suspending the tube of vapour of ether in liquid ether the vapour pointed axially

2416 In every kind of trial therefore and

ther, whatever the chemical or other properties of the substances however different in their specific gravity or however varied in their own degree of rarefaction they all become alike in their magnetic relation and apparently equivalent to a perfect vacuum Bodies which are very marked as diamagnetic substances immediately lose all traces of this character when they become vaporous (2415) It would be exceedingly interesting to know whether a body from the magnetic class as chloride of iron would undergo the same change

¶ vii *General Considerations*

2417 Such are the facts which in addition to those presented by the phenomena of light establish a magnetic action or condition of matter new to our knowledge Under this action

taneously subject to this power may be made to approach each other as if they were mutually attracted or recede as if mutually repelled All the phenomena resolve themselves into this that a portion of such matter when under magnetic action tends to move from stronger to weaker places or points of force When the substance is surrounded by lines of magnetic force of equal power on all sides *it does not* tend to move and is then in marked contradistinction with a linear current of electricity under the same circumstances

2419 This condition and effect are new *not only* in respect to the exertion of power by a

certain degree was known to possess

2420 All matter appears to be subject to the magnetic force as universally as it is to the gravitating the electric and the chemical or cohesive forces, for that which is not affected by it in the manner of ordinary magnetic action is affected in the manner I have now described

ing in degree, that where a substance from the one class will be attracted a body from the other will be repelled and where a bar of the one will assume a certain position, a bar of the other will acquire a position at right angles to it

2421 As yet I have not found a single solid

ation of magnetic action to know if there were any natural simple substance possessing this condition in the solid or fluid state Of compound or mixed bodies there may be many, and as it may be important to the advancement of experimental investigation I will describe the principles on which such a substance was prepared when required for use as a circumambient medium

2422 It is manifest that the properties of

ate degree of the property of either may be obtained Protosulphate of iron belongs to the magnetic and water to the diamagnetic class, and using these substances, I found it easy to make a solution which was neither attracted nor repelled, nor pointed when in air Such a solution pointed axially when surrounded by water If made somewhat weaker in respect of the iron, it would point axially in water but equatorially in air, and it could be made to pass more and more into the magnetic or the diamagnetic class by the addition of more sulphate of iron or more water

2423 Thus a *fluid* medium was obtained, which, practically as far as I could perceive had every magnetic character and effect of a gas and even of a vacuum, and as we possess both magnetic and diamagnetic glass (2354), it is evidently possible to prepare a *solid* substance possessing the same neutral magnetic character

2424 The endeavour to form a general list of substances in the present imperfect state of our knowledge would be very premature the one below is given therefore only for the purpose of conveying an idea of the singular association under which bodies come in relation to magnetic force and for the purpose of general reference hereafter

Iron
Nickel
Cobalt
Manganese
Palladium
Crown glass
Platinum
Osmium
0° Air and vacuum
Arsenic
Ether
Alcohol
Gold
Water
Mercury
Flint-glass
Tin
Heavy glass
Antimony
Phosphorus
Bismuth

2425 It is very interesting to observe that metals are the substances which stand at the

er for electricity At the same time the *contrast* between these metals, as to their fibrous and granular state, their malleable and brittle char-

acter, will press upon the mind whilst contemplating the possible condition of their molecules when subjected to magnetic force

2426 In reference to the metals, as well as the diamagnetics not of that class (2286), it is satisfactory to have such an answer to the opinion that all bodies are magnetic as iron, as does not consist in a mere negation of that which is affirmed, but in proofs that they are in a different and opposed state, and are able to counteract a very considerable degree of magnetic force (2448)

[illegible]

that when it causes the attraction of the one it produces the repulsion of the other, and this we cannot help referring, in some way, to an action upon the molecules or the mass of the substances acted upon, by which they are thrown into different conditions and affected accordingly In that point of view it is very striking to compare the results with those which are presented to us by a polarized ray, especially as then a remarkable difference comes into view, for if transparent bodies be taken from the two classes, as for instance, heavy glass or water from the diamagnetic, and a piece of green glass or a solution of green vit-

[illegible]

same line of force, which thus affects the particles so differently, affects the polarized ray when passing through them precisely in the *same* manner in both cases, for the two bodies cause its rotation in the *same* direction (2160, 2199, 2224)

2428 This consideration becomes even more important when we connect it with the diamagnetic and the optical properties of bodies which rotate a polarized ray Thus the iron solution and a piece of quartz, having the power to rotate a ray, point by the influence of the *same* line of magnetic force, the one axially and the other equatorially, but the rotation which

[illegible]

of quartz (or two tubes of oil of turpentine) be taken which can rotate the ray *different* ways, the further rotative force manifested by them

[illegible]

trast between the quartz as a diamagnetic, and the solution of iron as a magnetic body remains undisturbed Certain considerations regarding the character of a ray, arising from these contrasts, press strongly on my mind, which, when I have had time to submit them to further experiment, I hope to present to the Society

[illegible]

actions of magnets on them, might be offered in the supposition that magnetic induction caused in them a contrary state to that which it produced in magnetic matter, i e, *that if a* particle of each kind of matter were placed in the magnetic field both would become magnetic, and each would have its axis parallel to

[illegible]

would result approximation in the one substance, recession in the other

2430 Upon Ampère s theory, this view would be equivalent to the supposition, that as cur-

[illegible]

diamagnetic bodies, the currents induced are

[illegible]

ductors at the *commencement* of the inducing current, and those in magnetic bodies *the same*

[illegible]

netic substances, because the hypothetical currents are supposed to exist not in the mass, but round the particles of the matter

2431 As far as experiment yet bears upon such a notion, we may observe, *that the* known inductive effects upon masses of *magnetic* and diamagnetic metals *are the same* If a straight rod of iron be carried across magnetic lines of force, or if it, or a helix of iron rods or wire, be held near a magnet, as the power in it rises,

electric currents are induced, which move through the bars or helix in certain determinate directions (38, 114, &c) If a bar or a helix of bismuth be employed under the same circumstances the currents are again induced, and precisely in the same direction as in the iron, so that here no difference occurs in the direction of the induced current, and not very much in its force, nothing like so much indeed as between the current induced in either of these metals and a metal taken from near the neutral point (2399) Still there is this difference remaining between the conditions of the experiment and the hypothetical case, that in the former the induction is manifested by *currents in the masses, whilst in the latter*, i e , *in* the special magnetic and diamagnetic effects, the currents, if they exist, are probably about the particles of the matter

it should show no change in its relations by rarefaction to any possible degree, or even

middle of the great series of bodies, and that all gases or vapours should be alike, from the rarest state of hydrogen to the densest state of carbonic acid, sulphurous acid, or ether vapour, *are points so striking*, as to presuade one at once that air must have a great and perhaps an active part to play in the physical and terrestrial arrangement of magnetic forces

away, and though it is easy to prepare a liquid *medium which shall act with other* bodies as air does (2422), still it is not truly in the same relation to them, neither does it allow of dilu-

guishable from the rest.

2434 It is also very remarkable to observe the apparent disappearance of magnetic condition and effect when bodies assume the vaporous or gaseous state, comparing it at the same time with the similar relation to light, for as yet no gas or vapour has been made to show any magnetic influence over the polarized ray, even by the use of powers far more than enough to manifest such action freely in liquid and solid bodies

2435 Whether the negative results obtained by the use of gases and vapours depend upon the smaller quantity of matter in a given volume, or whether they are direct consequences of the altered physical condition of the substance, *is a point of very great importance to* the theory of magnetism I have imagined in elucidation of the subject, an experiment with one of M Cagniard de la Tour's ether tubes, but expect to find great difficulty in carrying it into execution, chiefly on account of the strength, and therefore the mass of the tube necessary to resist the expansion of the in-

latter Or, if the experiment presents its results

to an axial position, but because it tended to that position with less force than the matter around it, so the question will enter the mind, whether the diamagnetics, when in air, are repelled and tend to the equatorial position for any other reason, than that the air is more magnetic than they are, and tends to occupy the axial space It is easy to perceive that if all bodies were magnetic in different degrees, forming one great series from end to end, with air in the middle of the series, the effects would

bismuth, goes from a strong to a weak point of action, may do so only because that substance, which is already at the place of weak action, tends to come to the place where the action is strong, just as in electrical induction the bodies best fitted to carry on the force are drawn into the shortest line of action And so air in water, or even under mercury, is, or appears to be, drawn towards the magnetic pole

magnetic, or at all events altering its situation in the list If such were the case, bodies that

2440 Such a view also would make mere space magnetic, and precisely to the same degree as air and gases Now though it may very well be, that space, air and gases, have the

and have thus presented us with a magnetic property new to our knowledge

2441 The amount of this power in diamagnetic substances seems to be very small, when estimated by its dynamic effect, but the mo-

mately known to us, other effects produced by it and other indicators and measurers of its

serve to make it manifest and indicate its operation It is very striking to observe the feeble condition of a helix when alone, and the astonishing force which, in giving and receiving it manifests by association with a piece of soft iron So also here we may hope for some analogous development of this element of power, so new as yet to our experience It cannot for a

pointed office, and that one which relates to

together, when manifested by masses of matter of equal magnitude!

2442 With a full conviction that the uses of this power in nature will be developed hereafter, and that they will prove, as all other natural results of force do, not merely important but essential, I will venture a few hasty observations

amount of influence upon the magnetic force It requires mere observation to be satisfied that

netics acquire, may be the very condition ... carries on and causes the transfer of force through them In former papers (1161, &c)[1] I

[1] *Philosophical Transactions* 1838 Part I

proposed a theory of electrical induction founded on the action of contiguous particles with *which I am* now even more content than at the time of its proposition and I then ventured to suggest that probably the lateral action of electrical currents which is equivalent to electrodynamic or *magnetic* action, was also conveyed onwards in a similar manner (1663, 1710, 1729, 1735) At that time I could discover no peculiar condition of the intervening or diamagnetic matter, but now that we are able to distinguish such an action, so *like* in its nature in bodies so *unlike* in theirs, and by that so like in character to the manner in which the magnetic force pervades all kinds of bodies, being at the same time as universal in its presence as it is in its action, now that diamagnetics are shown not to be indifferent bodies, I feel still more confidence in repeating the same suggestion, and [illegible] whether the peculiar condition acquired by diamagnetics when subject to magnetic action, is not that condition by which such propagation of the force is affected?

2444 Whichever view we take of solid and liquid substances, whether as forming two lists, or one great magnetic class (2424, 2437), it will *not, as far as I can perceive, affect the question* They are all subject to the influence of the magnetic lines of force passing through them, and the virtual difference in property [illegible]

[illegible] sents any difficulty to the mind, but here there is such a wonderful change in the physical constitution of the bodies, and such high powers in some respects are retained by them, whilst others seem to vanish, that we might almost expect some peculiar condition to be assumed in regard to a power so universal as the magnetic force Electric induction being an action [illegible]

[illegible] neither does it vary in degree in air however rare or dense it may be (1284) Now magnetic action may be considered as a mere function of electric force, and if it should be found to correspond with the latter in this particular relation to air, gases, &c, it would not excite in my mind any surprise

2446 In reference to the manner in which it is possible for electric force, either static or dynamic, to be transferred from particle to particle when they are at a distance from each other, or across a vacuum, I have nothing to add to what I have said before (1614, &c) The supposition that such can take place, can present nothing startling to the mind of those who have endeavoured to comprehend the radiation and the conduction of heat under one principle of action

2447 When we consider the magnetic condition of the earth as a whole, without reference to its possible relation to the sun, and reflect upon the enormous amount of diamagnetic matters which, to our knowledge, forms its crust, and when we remember that magnetic curves of a certain amount of force and universal in their presence, are passing through these matters and keeping them constantly in that state of tension, and therefore of action, which I hope successfully to have developed, we cannot doubt but that some great purpose of utility to the system, and us its inhabitants, is thereby fulfilled, which now we shall have the pleasure of searching out

2448 Of the substances which compose the *crust of the earth, by far the greater portion* [illegible]

[illegible] them, and as respects the rocks and mountains, [illegible]

[illegible] is, by a due association of the forces of a body from each class, water and a salt of iron, the [illegible]

it It is not therefore at all unlikely that many of the masses which form the crust of this our globe may have an excess of diamagnetic power and act accordingly

2449 Though the general disposition of the

diverging in their general form, yet the magnitude of the system prevents us from observing any diminution of their power within small limits so that probably any attempt on the surface of the earth to observe the tendency of

or of water, estimated at the equator, where the magnetic needle does not dip, ought to weigh less when taken into latitudes where the dip is considerable, whilst a pound of iron,

and another of bismuth, attached to the ends of a delicate balance beam, should cause that beam to take different inclinations on different parts of the surface of the earth, and it does not seem quite impossible that an instrument to measure one of the conditions of terrestrial magnetic force might be constructed on such a principle

2450 If one might speculate upon the effect of the whole system of curves upon very large masses, and these masses were in plates or rings, then they would, according to analogy with the magnetic field place themselves equatorially If Saturn were a magnet as the earth is, and his ring composed of diamagnetic substances, the tendency of the magnetic forces would be to place it in the position which it actually has

by future observation

2452 Of the interior of the earth we know nothing, but there are many reasons for believing that it is of a high temperature On this supposition I have recently remarked, that at a certain distance from the surface downwards, magnetic substances must be entirely destitute, either of the power of retaining magnetism, or becoming magnetic by induction from currents in the crust or otherwise [1] This is evidently an error, that the iron, &c, can retain no magnetic condition of itself, is very probably true, but that the magnetic metals and all their compounds retain a certain power of becoming magnetic by induction, whatever their temperature, has now been proved (2344, &c) The deep magnetic contents of the earth, therefore, though they probably do not constitute of themselves a central magnet, are just in the condition to act as a very weak iron core to the currents around them, or other inducing actions, and very likely are highly important in this respect What the effect of the diamagnetic part may be under the influence of such inductive forces, we are not prepared to state, but as far as I have been able to observe, such bodies have not their power diminished by heat (2397)

2453 If the sun has anything to do with the magnetism of the globe, then it is probable that part of its effect is due to the action of the light that comes to us from it, and in that expectation the air seems most strikingly placed

seem to suggest the possibility of magnetism being there generated, but I shall do better to

ciety

Royal Institution, Dec 22, 1845

Feb 2, 1846 I add the following notes and references to these *Researches*

Brugmans first observed the repulsion of bismuth

Seebeck on the Magnetic Polarity of different Metals Alloys and Oxides *Ibid* 1828 Vol IV p 175

[1] *Philosophical Magazine* 1845 Vol XXVII, p 3.

TWENTY-SECOND SERIES[1]

§ 28 *On the Crystalline Polarity of Bismuth (and Other Bodies), and on its Relation to the Magnetic Form of Force* ¶ i. *Crystalline Polarity of Bismuth* ¶ ii *Crystalline Polarity of Antimony* ¶ iii. *Crystalline Polarity of Arsenic*

RECEIVED OCTOBER 4, READ DECEMBER 7, 1848

2454 MANY results obtained by subjecting bismuth to the action of the magnet have at various times embarrassed me, and I have either been contented with an imperfect explanation, or have left them for a future examination that examination I have now taken up, and it has led to the discovery of the following results I cannot, however, better enter upon the subject than by a brief description of the anomalies which occurred, and which may be obtained at pleasure

2455 If a small open glass tube have a bulb formed in its middle part and some clean good bismuth be placed in the bulb and melted by a spirit-lamp, it is easy afterward, by turning the metal into the tubular part of the arrangement, to cast it into long cylinders these are very clean, and when broken are seen to be crystallized, usually giving cleavage planes, which run across the metal I prepare them from 0 05 to 0 1 of an inch in diameter, and, if the glass be thin, usually break both it and the bismuth together, and then keep the little cylinders in their vitreous cases

single magnetic pole, or passing off on either side from the axial line between two poles A similar piece of finely-grained or granular bis

muth was, under the same circumstances and at the same time, affected in a perfectly regular manner, taking up the equatorial position (2253), as a body simply diamagnetic ought to do The cause of these variations was finally traced to the regularly crystalline condition of the metallic cylinders

¶ i *Crystalline Polarity of Bismuth*

2457 Some bismuth was crystallized in the usual manner by melting it in a clean iron ladle, allowing it partly to congeal and then pouring away the internal fluid portion Pieces so obtained were then broken up by copper ham-

away by rubbing on sandstone and sandpaper Pieces weighing from 18 grains to 100 grains were thus easily obtained

from 12 to 24 inches in length, was attached to a fit support above, and made fast below to the end of a piece of fine, straight, well-cleaned

to adhere by pressure to any dry substance, and sufficiently hard to sustain weights up to 300 grains, or even more When prepared, the

[1] *Philosophical Transactions* 1849 p. 1 The Bakerian Lecture.

suspender was subjected by itself to the action of the magnet, to ascertain that it was free from any tendency to point, or be affected, without which precaution no confidence could be reposed in the results of the experiments

2459 A piece of selected bismuth (2457), weighing 25 grains was hung up between the poles of the magnet, and moved with great freedom The constituent cubes were associated in the usual manner being attached to each other chiefly in the line joining two opposite solid angles and this line was in the greatest length of the piece The instant that the magnetic force was on, the bismuth vibrated strongly about a given line, in which, at last, it settled, and if moved out of that position, it returned, when at liberty, into it pointing with considerable force, and having its greatest length *axial*

2460 Another piece was then selected, hav-

rial still the line according to which the cubes tended to associate diametrally, was, as before, in the *axial* direction Other pieces were then taken of different forms, or shaped into various forms by rubbing them down on stone, but they all pointed well, and took up a final position, which had no reference to the shape, but was manifestly dependent on the crystal [illegible] of the substance

[illegible] was dia- *mag-*

netic pole, or from [illegible] fected only whilst the magnetic force was present It set in a given constant position perfectly determinate, and, if moved, always returned to it, unless the extent of motion was above 90°, and then the piece moved farther round and [illegible] position diametrically opposed [illegible]

diametral set or position

2462 The effect occurs with a single magnetic pole, and it is then striking to observe a

2463 Whether the magnetic poles employed (2138) are pointed, round, or flatfaced, still the effect on the bismuth is the same nevertheless, the form of the poles has an important influence of a subordinate kind, and some forms [illegible] more fitted for these investigations [illegible] employed

[illegible] pole but [illegible] h the lines [illegible] tensity at and towards the edges [illegible] faces, yet there is a space at the middle of the magnetic field where they may be considered as parallel to the magnetic axes, and of equal force throughout If the flat faces of the poles be square or circular, and their distance apart about one-third of their diameter, this space of uniform power is of considerable extent In my experience the central or axial portion of the mag [illegible] sensibly weaker than the circum [illegible] small screw- [illegible] or the attachment of other [illegible] on

2464 Now the law of action of bismuth, as a *diamagnetic* body, is that it tends to go from stronger to weaker places of magnetic force (2267, 2418), but as a *magnecrystallic* body it is subject to no effect of the kind, and is as powerfully affected by lines of equal force as by any other So a piece of amorphous bismuth, suspended in a magnetic field of uniform power, seems to have lost its diamagnetic force altogether, and tends to acquire no motion but what is due to torsion of the suspending fibre, or currents of air but a piece of regularly crystallized bismuth is, in the same situation, very powerfully affected by virtue of its magnecrystallic condition

2465 Hence the great value of a magnetic field of uniform force, and, if, hereafter, in the

could easily be given by making the form of the pole face somewhat convex, and rounded at the edges more or less The required shape could be ascertained by calculation, or perhaps better in practice, by the use of a little test cylinder of bismuth in the granular or amorphous state, or of phosphorus

2466 In addition to these observations, it may be remarked that small crystals, or masses of crystals, and such as approach in their general shape to that of a cube or a sphere, are [illegible] inasmuch

affected by them

2467 When the crystal of bismuth is in a magnetic field of equal strength, it is equally affected whether it be in the middle of the field or close up to one or the other magnetic pole, i e the number of vibrations in equal times appears to be equal Much care, however, is required in estimating it by such means, because, from the occurrence of two positions of unstable equilibrium in the equatorial direction, the vibrations in large arcs are much slower than those in small arcs, and it is difficult in different cases to adjust them to the same extent of vibration

2468 Whether the bismuth be in a field of intense magnetic force or one of feeble powers, whether the magnetic poles are close up to the piece, or are opened out until they are five or six inches or even a foot asunder, whether the bismuth be in the line of maximum force, or raised above, or lowered beneath it, whether the electric current be strong or weak, and the magnetic force, therefore, more or less in that respect, if the bismuth be affected at all it is always affected in the same manner

2470 The direction of this force is, in rela-

nal plane (2252), so that when again freely suspended, the line through the crystal, which was before horizontal in the equatorial plane, was now vertical, the piece again pointed, and generally with more force than before The line passing through the crystal, coincident with the magnetic axis, may now be taken as a line of force, and if the process of a quarter revolution in the equatorial plane be repeated, however often, the crystal still continues to point with the assumed line of force in the magnetic axis, and with a maximum degree of power. But now, if the point of suspension be removed 90° in the plane of the axis, i e, to the end of the assumed line of force, so, that when the crystal is again freely suspended this line is vertical, then, the crystal presents its peculiar

2471 Now if the power had been equatorial and polar, its maximum effect would not have been produced by a change of the point of suspension through 90° in the equatorial plane, but by the same change in the axial plane, and any similar change after that in the axial plane, would not have disturbed the maximum force, whereas a single change of 90° in the equatorial plane, would have brought the line of force vertical (as in Plucker's case of Iceland spar), and reduced the results to a minimum or zero

2472 The directing force, therefore, and the set of the crystal are in the *axial* direction This force is, doubtless, resident in the particles of the crystal It is such, that the crystal can set with equal readiness and permanence in two diametral positions, and that between these

cules is, to all intents and purposes, both in

my own mind, I have found the meaning belonging to the former words the more useful

cubes My measurements were very imperfect and the crystals not regular, but as an average of several observations, the planes were inclined to each other at angles of 91½° and 88½°, and the boundary lines of a plane at 87½° and 92½°. Whatever be the true form, it

is manifest, upon inspection, that the aggregating force tends to produce crystals having more or less of the rhomboidal shape and rhombic planes, and that these crystals run together

with this direction where the latter is apparent

2475 The *cleavage* of bismuth crystals removes the solid angles and replaces them by planes, so that there are four directions producing the octohedron These cleavages are not (in my experience) made with equal facility, nor do they produce planes equally bright and perfect Two, and more frequently one, of these planes are more perfect than the others, and this, the most perfect plane is that which

and this plane corresponds to the one which I have already described as being generally the most perfect, and replacing the acute angle of the crystal

2476 A single crystal of bismuth was selected and cut out from the mass by copper tools, and the places where it had adhered were rubbed down on sand paper, so as to give the fragment a cube-like form with six planes, *four of these* planes were natural One of the solid angles, expected to be that terminating or in the di-

with this plane vertical, the crystal instantly pointed with considerable force, and with the plane towards either one or the other magnetic pole, so that the magnecrystallic axis appeared now to be horizontal and acting with its greatest power When this axial line was made vertical, and the plane therefore horizontal, the

magnetic axis and, finally, when the bright

cleavage plane was horizontal and the line of directive force therefore vertical, inclining it a little in a given direction would make any given part of the crystal point to the magnetic poles

2477 A *group* of bismuth crystals, the apex of which was terminated by a single small cleav-

imum degree of force It is very unlikely, however, that all the groups should be perfectly symmetric in the arrangement of their parts It is more surprising that they should be so distinct in their action as they are In reference to bismuth, and many other bodies, it is probable

can do

2479 I have already stated that the *magnecrystallic* force does not manifest itself by attraction or repulsion, or, at least, does not

the resultant of the action of all the molecules), *tends to place itself parallel, or as a tangent, to the magnetic curve or line of magnetic force, passing through the place where the crystal is situated*

2480 I now broke up masses of bismuth

but thicker plates or angular pieces often proved complicated in the results, though apparently simple and regular as to form Occasionally, the cleavage plane, which I have hitherto taken for that perpendicular to the line of force (2475), has proved not to be the plane supposed, but, after observing experimentally the direction of the magnecrystallic power, I have always either found, or else obtained by cleav-

bounded by parallel and similar planes, when

broken up, often proved, upon ocular examination, to be compounded and irregular

2481 When a well-selected plate of bismuth (mine are about 0 3 of an inch in length and breadth and 0 05, more or less in thickness) is hung up by the edge in the magnetic field it vibrates and points, presenting its faces to the magnetic poles and setting diametrally (2461) By whatever part of the edge it is suspended, the same results follow But if it be suspended horizontally, the cleavage planes of the fragment and of the magnetic axis being parallel to the plane of motion of the plate, then it is perfectly indifferent for then the line of magnecrystallic force is perpendicular to the line of magnetic force in every position that it can take

2482 But if the plate be inclined at only a very small angle from this position it points, and that with more force as the planes become more nearly vertical (2475), and the phenomena before described with a crystal (2476), can here be obtained with a fragment from a mass, and any part of the edge of the plate made to point axially, by elevating or depressing it above or below the horizontal plane

2483 *If a number of these crystalline plates* be selected at the magnet, they may after

diamagnetic effect of the bismuth may be neu-

has lost all power of pointing under the influ-

fragments or powder into a tube, and submitting the whole to the force of the magnet

2485 These experiments on bismuth are not difficult of repetition, for, except those which require the sudden production or cessation of the magnetic force the whole may be repeated with an ordinary horseshoe magnet A magnet, with which I have wrought considerably, consists of seven bars placed side by side and being fixed in a box with the poles upwards, presents two magnet cheeks an inch and a

ication of particles of iron or rust The best place for the piece of bismuth is, of course, between the poles, not level however, with their tops but from 0 4 to 1 0 inch lower down (2463), that the effect of flat-faced poles may be ob-

field between them

2486 The magnet I used would sustain 30 lbs at the keeper, but employing small pieces of bismuth, I have easily obtained the effects *with magnets weighing themselves not more* than 7 ounces, and able to sustain only 22 ounces so that the experiments are within the reach of every one

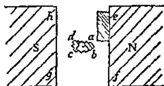


Fig 1

manner Let *Fig 1* represent in plan the position of the two chief magnetic poles and of a piece of crystallized bismuth between them, which by *its magnecrystallic condition, points* axially Then if a piece of soft iron be applied against

held between it and the bismuth so as to represent generally the same positions, the same effects, but in a weaker degree, are produced

2488 Though these motions seem to indicate an effect of attraction, I do not believe them to be due to any such cause, but simply to the influence of the law of action (2479) before expressed The previously uniform condition of the magnetic field is destroyed by the presence of the iron lines of magnetic force, of

proximating more or less to the conical or pointed form), and therefore the crystal of bismuth moves round on the axis of suspension, that it may place the line of magnecrystallic force parallel or as a tangent to the resultant of the

ployed, the appearances produced under similar circumstances, are those of *repulsion* for if *Fig 2* be allowed to represent this state of

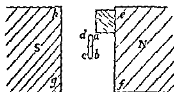


Fig 2

the law before expressed (2479), to place the magnecrystallic line of force parallel to, or as a

end *e* were inclined to either pole, the plate began to move, and moved most when the iron touched the pole as in the figure When it approached or touched the N pole, the inclination of the crystal plate of bismuth was as indicated by the dotted figure When it touched the S, the inclination was the contrary way If the end *e* were kept in contact with the N pole,

and the other end of the soft iron rod placed in the position *m*, the bismuth was not affected, but if then this subsidiary pole were moved the one way or the other towards the edge of the plate, the latter turned as the pole moved,

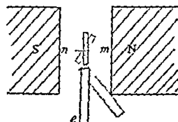


Fig 3

always tending to keep its face towards it, and evidently by the tendency of the magnecrystallic axis to place itself parallel to the resultant of magnetic force passing through the bismuth The same results were obtained with the crystal (2487) under similar circumstances, and corresponding results were obtained when the soft iron rod was applied between the S cheek of the magnet and the bismuth The like effects were also obtained with plates of arsenic and antimony

2491 When a magnet is used instead of soft

suspended between the cheeks of the horse-

part of the bismuth near it, and precisely for the same reasons as those that existed when

the manner represented by the motion of the bismuth, in its tendency to place its line of force parallel with them in their new position

2493 An approximated south pole caused motions in the contrary direction

2494 When the subordinate pole was ap-

muth than when the plate was used

2495 Innumerable variations of these motions may be caused and appearances of attraction or repulsion or tangential action be obtained at pleasure by the use of crystals having the magnecrystallic axis corresponding with their length or plates where it accords with their thickness and either permanent or temporary subsidiary magnetic poles By making the moveable pole travel slowly round the bismuth from the neutral point *m* to the other neutral point *n* *Fig 3* a summary of the whole can be obtained and it is found that they all

muth (or arsenic [2532]) may become a very useful and important indicator of the direction of the lines of force in a magnetic field for at the same time that it takes up a position showing their course it does not by its own action tend sensibly to disturb them

2497 Many of these motions are similar to and have relation with those described by [illegible]

[illegible] I am not acquai[illegible]ted with all of them [illegible] with the reasoning thereon (being in the German language) but such as I am aware of and

to proceed from stronger to weaker places of magnetic force and give no additional or other proof of the assumed reverse polarity of bismuth than the former cases of action which I had given coming under that law

2498 S[illegible]

distance (about two inches) asunder suspended a crystal of bismuth in the middle of the magnetic field and observed its vibrations and set Then without any other change I introduced screens of bismuth being blocks about two inches square and 0 75 of an inch in thickness between the poles and the crystal but I could not perceive that any change in the phenomena was produced by their presence

2499 The bismuth crystal (2459) was suspended in water between the magnetic poles of the horseshoe magnet It set well in accordance with the general law (2479) and it took five revolutions of the torsion index at the upper end of the suspending silk filament to displace it and cause it to turn into the diametral position This is as well as I could observe the results the same amount of torsion force required to effect its displacement when the crystal was placed in the same position but surrounded with air only

2500 The same bismuth was then suspended in a saturated solution of protosulphate of iron (adapted as a magnetic medium) it set as before with apparently no change of any kind and when the torsion force was put on it still required five turns of the index as before to cause the displacement of the crystal and its passage into the diametral position

2501 Whether therefore crystals of bismuth be immersed in air or water or solution of sulphate of iron or placed between thick masses of bismuth if they be subject to the same magnetic force the magnecrystallic force exerted by them is the same both in nature direction and amount

2502 It seemed possible and probable that magnetic force might affect the crystallization of bismuth if not of other bodies For as the force affects the mass of a crystal by that power which its particles possess and which they give

under the influence of the magnetism, the

dividual particles would tend to assume one and the same axial condition, and the crystalline arrangement and direction of the mass upon its solidification, be in some degree determined and under government

2503 Some bismuth, therefore, was fused in a glass tube and held in a fixed position in the strong magnetic field until it had become solid, then, being removed from the glass, it was suspended so that it might assume the same posi

regularly crystallized but that a *difference* between one direction and another might appear Nothing of the kind however occurred, whatever the direction in which the piece was suspended and when it was broken open the crystallization within was found to be small,

2504 I cannot find that crystals of bismuth acquire any power, either temporary or permanent, which they can *bring away* from the magnetic field I held crystals in different positions in the field of intense action of a powerful electro-magnet, having conical terminations very near to each other, and, after some time, removed them and applied them instantly to a very delicate astatic magnetic needle, but I could not perceive that they had the least extra effect upon it, because of such treatment

2505 As a crystal of bismuth is subject to,

from currents of air by concentric glass tubes, and I think have observed indications of a set or pointing The crystal was so hung that the

ments require careful repetition

crystallized masses of bismuth, can mutually affect each other, and if so, what the nature of these affections are? what is the relation of the equatorial and terminal parts? and what, the direction of the forces? I have made many experiments, in relation to this subject, both in and out of the magnetic field, but obtained only negative results I employed however small masses of bismuth, and it is my purpose to repeat and extend them at a more convenient season with larger masses, built up, if necessary, in the manner already described (2483)

2507 I need hardly say that a crystal of bismuth ought to point in a helix or ring of wire carrying an electric current, and so that its magnecrystallic axis should be parallel to the axis of the ring or helix This I find experimentally to be the case

¶ ii *Crystalline Polarity of Antimony*

2508 *Antimony* is a *magnecrystallic* body Some crystalline masses, procured in the manner before described (2457), were broken up with copper tools, and some excellent groups of crystals were obtained, weighing from ten to twenty grains each, in which all the constituent crystals appeared to be uniformly placed The individual crystals were very good on the whole, and much more frequently complete and full at the faces than those of bismuth They were

selves Planes of cleavage can be made to replace the solid angles, and, as with bismuth, there is one plane generally brighter and more nearly perfect than the others

2509 In the first place, it was ascertained that all these crystals were diamagnetic and strongly so

2510 In the next it was ascertained, as with

lel to the resultant of magnetic force passing through the crystal (2479) This line proceeded, as in bismuth, from one of the solid angles to the opposite one, and was perpendicular to the bright cleavage plane just spoken of (2508)

2511 So, generally, the action of the magnet upon these crystals was the same as upon

the crystals of bismuth, but there are some points of variation which require to be more distinctly stated and distinguished

2512 In the first place, when the magnecrystallic axis was horizontal, and a certain crystal used, upon the evolution of the magnetic force, the crystal went up to its position slowly, and pointed, as with a dead set If the crystal were moved from this position on either side, it returned to it at once there was no vibration Other crystals did the same imperfectly, and others again made one or perhaps two vibrations, but all appeared as if they were moving in a thick fluid, and were, in that respect, utterly unlike bismuth, in the freedom and mobility with which it vibrated (2459)

2513 In the next place, when the crystals were so suspended as to have the magnecrystallic axis vertical, there was no pointing nor any other signs of magnecrystallic force, but [illegible]

if the greatest length was out of the axial or equatorial position, the arrest was followed by a *revulsive* motion on the discontinuance of the electric current (2315) This revulsive motion [illegible]

former occasion with copper and other metals (2309), and due to the same cause, namely, the production of circular electric currents in the [illegible]

rents produced by the motion are just those which tend to stop the motion (2329),[1] and though the magnecrystallic force was sufficient to make the crystal move and point, yet the very motion so produced generated the current which reacted upon the tendency to motion, and so caused the mass to advance towards its position of rest as if it moved in a thick fluid

2515 Having this additional knowledge respecting the arrest and revulsion of the antimony (effects dependent upon its superior conducting power in this compact crystalline state, as compared with bismuth), one has no difficulty in identifying the magnecrystallic force of this metal with that of the former, and establishing the correspondence of the results in all essential characters and particulars In most of the pieces of crystals of antimony the force seemed less than in bismuth, but in fact, this may not really be so, for the inductive current action just described tends to hide the magnecrystallic phenomena

2516 Different pieces of antimony also seem to differ from each other in their setting force, and also in their tendency to exhibit revulsive effects but these differences are either only apparent or may easily be explained The arresting and revulsive action depends much upon the continuity of the mass, so that one large piece shows it much better than several small pieces, and these again better than a powdered substance Even the revulsive action of copper may be entirely destroyed by reducing the single lump to filings It is easy to perceive therefore, that of two groups of antimony crystals each symmetrically disposed within itself, the one may have larger crystals well connected together, as regards the induction of currents through the whole mass, and the other smaller crystals less favourably united These would present very different appearances, as regards the arrest of motion and succeeding revulsive action and further, on that very account, [illegible]

dence of the existence of the magnecrystallic [illegible]

wards the magnetic poles, and the plate oscillated on each side of its final position, gradually acquiring its state of rest.

[1] Anyone who wishes to form a sufficient idea of the arresting powers of these induced currents [illegible]

2518 When these plates were suspended with their planes horizontal, they had no power of pointing in the magnetic field When they were inclined, the points which were most depressed below and raised above the horizontal plane, were those which took up their places nearest the magnetic poles (2482)

ready a characteristic

2520 Thus it is evident that, in all these cases, there was a line of magnecrystallic force perpendicular to the planes of the plates, and *perfectly consistent in its position and action* with the force before found in the solid crystals of antimony

2521 But another plate of antimony was now selected, which had every appearance of being able to present all the phenomena of the former plates, and yet, when hung up by its edge, it showed no signs of magnecrystallic results, for it first advanced a little (2310), then was arrested and kept in its place, and if standing between the axial and equatorial positions, was revulsed when the battery current was in

2522 When this plate (2521) was placed in the field of intense power between two *conical*

position, a result which was probably due to the exertion of both *magnecrystallic* and *diamagnetic* force When the plate was suspended with its planes horizontal, the arresting and revulsive actions were gone, for the induced currents which before caused them could not now exist in the necessary vertical plane, further, it had no setting power, which showed that there was no axis of magnecrystallic force in the

freely, pointed well, and presented no indication of the arrest and revulsive phenomena Others vibrated sluggishly, set well, and showed

once, did not set (within the time of my ob-

that sometimes a plate of antimony being selected (2517), having planes very bright and perfect in their appearance, and, therefore, giving reason to think that it may point well in the magnetic field, when submitted to the horse shoe magnet does not do so, but points obliquely, feebly, and perhaps in two undiametral positions This is, I have no doubt, because *the crystallization is complicated and confused* Such a plate, if it be sufficiently broad and

2526 In the next place, we have to remember that, for the development of the induced

The currents occur in the mass and not round

currents are produced Hence the reason why the effect does not occur with plates suspended in the horizontal position, which yet produce it well in the vertical position, a result which a disc half an inch in diameter of thin foil or plate, being copper, silver, gold tin, or almost any malleable metal, will show, though the best conductors are the fittest for the purpose Now this condition is of no consequence in respect to *magnecrystallic* action, and a narrow plate has as much force as a broad one, having the same mass The first plate that I happened to select (2517) was well crystallized, thick and narrow, hence it was favourable for magnecrystallic action, unfavourable to the arresting and revulsive action, and showed no signs, comparatively, of the latter

2527 When a broad and well-crystallized plate is obtained, then both sets of effects appear thus, if the plate is revolving when the magnetic force is brought into action, it quickens its velocity for an instant, then is stopped and if the magnetic force is at once taken off, it is revulsed, exactly as a piece of copper would be (2315) But if the magnetic force be continued, it will then be perceived that the stop

Hence the magnecrystallic force is there and produces its full effect and the reason why the appearances have changed is that the very motion which the force tends to give and does give to the mass causes those magneto-electric currents (2329) which by their mutual action with the magnet tends to stop the motion and therefore its slowness and the final dead set (2512 2523)

2528 A magnet which is weaker (as the horse-shoe instrument described [2485]) produces the currents by induction in a much weaker degree and yet manifests the magnecrystallic power well hence it is more favourable under certain circumstances for such investigations as it helps to distinguish the one effect from the other

2529 It will readily be seen that plates whether of the same metal or of different metals cannot even roughly be compared with each other as to magnecrystallic force by their vibrations for under the influence of these induced currents plates of the same magnecrystallic force oscillate in very different manners I took a plate and by cement (2458) attached selected paper to its faces and then observed

crystals of antimony (2508) showed the effect in such a degree as to make me think that the constituent cubes possessed the power nearly equally in all directions A piece of finely crystallized or granular antimony does not however show it in the same proportion from which it would seem as if an effect equivalent in some degree to that of division occurs either

rections

¶ iii *Crystalline Polarity of Arsenic*

2532 A mass of the metal arsenic exhibiting crystalline structure (2480) was broken up and several plates selected from the fragments having good cleavage plane surfaces about 0 3 of an inch in length 0 1 inch in width and 0 03 in thickness These when suspended op-

centre of the faces and these so much weaken the intensity of the lines of magnetic force about the middle of the field when the faces

(2482 2518)

2534 Thus arsenic with bismuth and antimony are found to possess the magnecrystallic force or condition

Royal Institution September 23 1848

TWENTY-SECOND SERIES, *Continued*[1]

§ 28. *On the Crystalline Polarity of Bismuth and Other Bodies, and on its Relation to the Magnetic and Electric Form of Force (continued)* ¶ iv *Crystalline Condition of Various Bodies* ¶ v. *Nature of the Magnecrystallic Force, and General Observations*

RECEIVED OCTOBER 31, READ DECEMBER 7, 1848

¶ iv *Crystalline Condition of Various Bodies*

2535 *ZINC* Plates of zinc broken out of crystallized masses gave irregular indications, and, being magnetic from the impurity in them, the effects might be due entirely to that circumstance Pure zinc was thrown down electro-chemically on platina from solutions of the chloride and the sulphate The former occurred in ramifying dendritic associations of small crystal, the latter in a compact close form Both were free from magnetic action and freely diamagnetic, but neither showed any trace of the magnecrystallic action

2536 *Titanium*[2] Some good crystals of titanium obtained from the bottom of an iron furnace, were cleansed by the alternate action of acids and fluxes until as clear from iron as I could procure them They were bright, well-formed and magnetic (2371), and contained iron, I think, diffused through their whole mass, for nitromuriatic acid, by long boiling, continually removed titanium and iron from them These crystals had a certain magnetic property which I am inclined to refer to their crystalline condition When between the poles of the elec-

the same position, showing that it was constantly rendered magnetic in the same direction But if a crystal was placed and kept in another position between the magnetic poles whilst the electric current was on, and afterwards the current suspended, and then the crystal set free, it pointed between the poles of the enfeebled magnet in this new direction, showing that the magnetism was in a different direction in the body of the crystal to that which it had before If now the magnet were reinvigorated by the electric current, the crystal instantly spun round and took a magnetic

they could be magnetized with a facility and force greater than in any other From the appearances I am inclined to refer this to the crystalline condition, but it may be due to an irregular diffusion of iron in the masses of titanium The crystals were too small for me to make out the point clearly

2537 *Copper* I selected some good crystals of native copper, and, having carefully separated them from the mass, examined them in respect of their magnecrystallic force At the horseshoe magnet (2480) they gave no signs of such power, whatever the direction in which they were suspended, but stood in any posi-

jected to the electro-magnet, the phenomena of arrest and revulsion were produced (2513,

necrystallic action in this case

2538 *Tin* I selected from block and grain tin some pieces which appeared, by their external forms and the surface produced under the action of acids, to have a regular crystalline structure internally, and, cutting off portions, carefully submitted them to the power

ing else I also examined some crystals of tin

[1] *Philosophical Transactions* 1849 p 19

[2] For these and many other crystals I am indebted to the kindness of Sir Henry T De la Beche and Mr Tennant.

obtained by electro-chemical deposition They were pure and diamagnetic they were arrested and revulsed, but they showed no signs of magnecrystallic action

2539 *Lead* Lead was crystallized by fusion, partial solidification, and pouring off (2457), and some very fair crystals, having the general form of octohedra, were obtained Observed at the magnets, these were arrested and revulsed feebly, but presented no magnecrystallic phenomena Some fine crystalline plates of lead obtained electro-chemically from the decomposition of the acetate by zinc, were submitted to the magnet they were pure, diamagnetic, and were arrested and revulsed but presented no appearance of magne...

not take place, because of their octohedral or orbicular form They presented no magnecrystallic indications

2541 *Tellurium* Two fractured pieces of this substance, presenting large and parallel planes of cleavage were examined both pointed and the greatest length was across the axial line between flat-faced poles (2463) I think the effects were in part if not altogether due to the magnecrystallic state of the substance but I do not think the evidence was quite conclusive

grains are thick Some of the largest and most crystalline were selected and after ignition

lected and examined more carefully These all

cles were *always* towards the poles and their length consequently not *in* but *across* the axial line, and this was true whether the distance between the poles was small or great, or whether flat-faced or conical poles were used I believe they were magnecrystallic

2543 *Fusible metal* Crystals of fusible metal (2457) pointed, but the crystals, which were apparently quadrangular plates or prisms, were not good, and the evidence not clear and distinct

2544 *Wires* I thought it possible that thin wires, which by the action of acids exhibited

iron, specular iron and magnetic oxide of iron were still more so I could not in any of them distinguish any magnetic results due to crystallization

force, and the greatest length went equatorially The crystal was compounded of superposed flat crystals or plates, and the magnecrystallic axis went directly across these it was

and determined the position of the crystal, and this happened whether pointed or flat poles were used, and whether they were near to-

constantly retained by the magnecrystallic axis, so greatly does it predominate in power over the mere magnetic force of the crystal Yet this latter is so great as at times to pull the suspending fibre asunder when the crystal is above the poles (2615)

2547 *Sulphate of nickel* When a crystal of sulphate of nickel was suspended in the magnetic field, its length set axially This might be due, either to mere magnetic force, or partly to magnecrystallic force Therefore I cut a cube out of the crystal, two faces of which were perpendicular to the length of the original prism This cube pointed well in the magnetic field, and the line coincident with the axis of the prism was that which pointed axially, and represented the magnecrystallic axis Even when the cube was reduced in this direction and converted into a square plate whose thickness coincided with the magnecrystallic axis, it pointed as well as before, though the shortest dimensions of the piece were now axial

2548 The *persulphate of ammonia and iron*, and the *sulphate of manganese*, did not give any indication of magnecrystallic phenomena, the *sulphate of ammonia and manganese* I think did, but the crystals were not good The sulphate of potassa and nickel is magnecrystallic All three salts were magnetic

2549 Thus it seems that other bodies besides bismuth, antimony and arsenic, present magnecrystallic effects Amongst these are the alloy of indium and osmium, probably tellurium and titanium, and certainly the sulphates of iron and nickel Before leaving this part of the subject, I may remark that this property has probably led me into error at times on a former occasion (2290) A mistake with arsenic (2383) might very easily arise from this cause

¶ v. *On the Nature of the Magnecrystallic Force, and General Observations*[1]

2550 The magnecrystallic force appears to be very clearly distinguished from either the magnetic or diamagnetic forces, in that it causes neither approach nor recession, consisting not in attraction or repulsion, but in its giving a certain determinate position to the mass under its influence, so that a given line in relation to the mass is brought by it into a given relation with the direction of the external magnetic power

2551 I thought it right very carefully to examine and prove the conclusion, that there was no connection of the force with either attractive or repulsive influences For this purpose I constructed a torsion balance, with a bifilar suspension of cocoon silk, consisting of two bundles of seven filaments each, 4 inches long and one-twelfth of an inch apart, and suspended a crystal of bismuth (2457) from one end of the lever, so that it might be fixed and retained in any position This balance was protected by a glass case, outside of which the conical terminal of one pole of the great electro magnet (2247) was adjusted, so as to be horizontal, at right angles to the lever of the torsion-balance, and in such a position that the bismuth crystal was in the prolongation of the axis of the pole, and about half an inch from its extremity when all was at rest The other pole, 4 inches off, was left large so that the lines of magnetic force should diverge, as it were, and rapidly diminish in strength from the end of the conical pole The object was to observe the degree of repulsion exerted by the magnet on the bismuth, as a diamagnetic body, either by the distance to which it was repelled, or by the torsion required to bring it back to its first position, and to do this with the bismuth, having its magnecrystallic axis at one time axial or parallel to the lines of magnetic force, at another equatorial, observing whether any difference was produced.

2552 The crystal was therefore placed with its magnecrystallic axis first parallel to the lines of magnetic force, and then turned four times in succession 90° in a horizontal plane, so as to observe it under all positions of the magnecrystallic axis, but in no case could any difference in the amount of the repulsion be observed. In other experiments the axis was placed oblique, but still with the same result If there be therefore any difference it must be exceedingly small[2]

2553 A corresponding experiment was made, hanging the crystal as a pendulum by a bifilar suspension of cocoon silk 30 feet in length, with the same result

2554 Another very striking series of proofs that the effect is not due to attraction or repulsion, was obtained in the following manner A skein of fifteen filaments of cocoon silk, about 14 inches long, was made fast above, and then a weight of an ounce or more hung to the lower end, the middle of this skein was about the middle of the magnetic field of the electro-magnet, and the square weight below rested against the side of a block of wood, so as to give a steady, silken vertical axis, without swing or revolution A small strip of card, about half

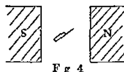
[1] See onwards, 2836, &c.

[2] See now 2839 &c.

an inch long and the tenth of an inch broad was fastened across the middle of this axis by cement and then a small prismatic crystal of sulphate of iron about 0 3 of an inch long and 0 1 in thickness was attached to the card so *that the length* and also the magnecrystallic axis were in the horizontal plane all the length was on one side of the silken axis so that as the

to the torsion force of the suspending skein of silk and the pos tion could be made any one that was des red by turning the weight below The torsion force was such that when the crystal was made to vibrate on its silken axis forty complete (or to and fro) vibrations were per formed in a minute

2556 When the crystal was made to stand between the flat faced poles (2463) obliquely as in *Fig 4* the moment the magnet was ex



F g 4

was removed and the experiment repeated the same effect took place but not as strongly as before and wl en finally the pole S was brought as near to the crystal as it could be without touching it the same result occurred and with more strength than in the last case

2557 In tl e two latter experiments there-

ne n a_gnecrysta c cond t on

2558 *If the pole S be removed and that* marked N be reta ned for action on tl e crystal

moval to a distance of the crystal just as tl e former did The experiment requires c re an l I find that con cal poles are not good but with attention I could obtain the results with the utmost readiness

2559 The sulphate of iron was then replaced by a crystalline plate (2480) of bismuth placed as before on one s de of the s lk suspender and with its magnecrystallic axis horizontal Mak ing the position the same as that which the *crystal had in relat* on *to the N* pole in the former experiment (2556) so that to place its axis parallel to the lines of magnet c force it

obtained with the red ferro pruss ate o po tassa A crystal of this salt had its acute linear angles ground away so as to convert it into a plate with faces parallel to the plane of the optic axis and was then made to replace the plate of b smuth Being in the position before represented (2556) and the magnet rendered active it moved placing *the plane of the optic* axes equatorially as Plucker describes When the pole N was removed and S brought up to the crystal the same mot on occurred the crys tal *retreating from* the pole and when S pole was removed and N brought towards the crys-

ent attractive and repuls ve force

2561 Hence a proof that neither attract on nor repulsion causes the set or governs tl e final pos tion of the body or of any of the bod es whose movements are due to tl e same cause (2607)

conclusion, namely, that as far as they can act on each other they partake of a like nature, and brings, I think, fresh help for the solution of that great problem in the philosophy of molecular forces, which assumes that they all have one common origin (2146)

2563 Whether we consider a crystal or a particle of bismuth, its polarity has a very extraordinary character, as compared with the polarity of a particle in the ordinary magnetic state, or when compared with any other of the dual conditions of physical force, for the opposite poles have *like* characters as is shown first of all by the diametral pointing of the masses (2461), and also by the physical characters and relations of crystals generally As the molecules lie in the mass of a crystal, therefore, they can in no way represent, or be represented by, the condition of a parcel of iron filings between the poles of a magnet, or the particles of iron in the keeper when in its place, for these have poles of *different* names and quality adhering together, and so giving a sort of structure, whereas, in the crystal the molecules have poles of like nature towards each other, for, so to say, all the poles are alike

2564 As made manifest by the phenomena, the magnecrystallic force is a force acting at a distance, for the crystal is moved by the magnet at a distance (2556, 2574), and the crystal also can move the magnet at a distance To produce the latter result, I converted a steel bodkin, about 3 inches long, into a magnet, and then suspended it perpendicularly by a single cocoon filament 4 inches long, from a small horizontal rod, which again was suspended by its centre and another length of cocoon filament, from a fixed point of support In this manner the bodkin was free to move on its own axis, and could also describe a circle about 1½ inches in diameter, and the latter motion was not hindered by any tendency of the needle to point under the earth's influence, because it could take any position in the circle and yet remain parallel to itself

2565 A support perfectly free from magnetic action was constructed of glass rod and copper wire, which passing through the bottom of the stand, and being in the prolongation of the upper axis of motion, was concentric with the circle which the little magnet could describe, its height was such that it could sustain a crystal or any other substance level with the pole at the lower end of the needle, and in the centre of the small circle in which the latter could revolve around it By moving the lower end of the support, the upper end also could be made to approach to or recede from the magnet The whole was covered with a glass shade, and when left to become of uniform temperature, and at rest, the needle magnet was found to take up a *constant* position under the torsion force of the suspending filaments Further, any rotation of the glass and copper wire support did not produce a final change in the position of the magnet, for though the motion of the air would carry the magnet away, it returned, ultimately, to the same spot When removed from this spot, the torsion force of the silk suspension made the system oscillate, the time of a half oscillation, or a passage in one direction, was about three minutes, and of a whole oscillation therefore six minutes

2566 When a crystal of bismuth was fixed on the support with the magnecrystallic axis in a horizontal direction, it could be placed near the lower pole of the magnet in any position, and being then left for two or three hours, or until by repeated examination the magnetic pole was found to be stationary, the place of the latter could be examined and the degree and direction in which it was affected by the bismuth ascertained Extreme precaution was required in these observations, and all steel or iron things, as spectacles, knives, keys, &c, had to be removed from the observer before he entered the place of experiment and glass candlesticks were used The effect produced was but small, but the result was, that if the direction of the magnecrystallic axis made an angle of 10°, 20°, or 30° with the line from the magnetic pole to the middle of the bismuth crystal, then the pole followed it, tending to bring the two lines into parallelism, and this it did whichever end of the magnecrystallic axis was towards the pole, or whichever side it was inclined to By moving the bismuth at successive times, the deviation of the magnetic pole could be carried up to 60°

2567 The crystal of bismuth therefore is able to react upon and affect the magnet at a distance

2568 But though it thus take up the character of a *force acting at a distance*, *still* it is due to that power of the particles which makes them cohere in regular order, and gives the mass its crystalline aggregation, which we call at other times the attraction of aggregation, and so often speak of as acting at *insensible* distances

2569 For the further explication of the nature of this force, I proceeded to examine the

effect of heat on crystals of bismuth when in the magnetic field The crystals were suspended either by platina or fine copper wire, and heated, sometimes by a small spirit lamp flame applied directly, sometimes in an oil-bath placed between the magnetic poles, and though the upward currents of air and fluid were strong in these cases, they were far too weak to overcome the set caused by magnecrystallic action, and helped rather to show when that action was weakened or ceased

2570 When the temperature was gradually raised in the air the bismuth crystal continued to point, until of a sudden it became indifferent in that respect, and turned in any direction under the influence of the rising currents of air Instantly removing the lamp flame the bismuth revolved slowly and regularly, as if there were no tendency to take up one position more than another, or no remains of magnecrystallic action, but in a few seconds, as the temperature fell, it resumed its power of pointing, and, apparently, in an instant and with full force, and the pointing was precisely in the same direction as at first On examining the crystal carefully, its external shape and its cleavage showed that, as a crystal, it was unchanged, but the appearance of a minute globule of bismuth, which had exuded upon the surface in one place, showed that the temperature had been close upon the point of fusion

2571 The same result occurred in the oil-bath, except that as removing the lamp from the oil bath did not immediately stop the addition of heat to the bismuth, so more of the latter was melted, and about one-fourth of the metal appeared as a drop hanging at the lower part Still the whole mass lost its power at the high temperature, and the power was regained in the same direction, but in a less degree on cooling The diminished force was accounted for on breaking up the crystal, for the parts which had been liquefied were now crystallized irregularly, and therefore, though active at the beginning of the experiment, were neutral at the end

2572. As heat has this effect, the expectation entertained (2502) of crystallizing bismuth regularly *in the magnetic field* is of course unfounded, for the metal must acquire the solid state, and be lowered through several degrees probably, before it can exhibit the magnecrystallic phenomena If heat has the same effect on all bodies prior to their liquefaction, then, of course, such a process can be applied to none of them.

2573 A crystallized piece of antimony was subjected to the same experiment, and it also lost its magnecrystallic power below a dull red heat, and just as it was softening so as to take the impression of the copper loop in which it was hung On being cooled it did not resume its former state, but then became ordinarily magnetic and pointed This I conclude arose from iron affected by the flame and heat of the spirit-lamp, for, as the heat was high enough to burn off part of the antimony and make it rise in fumes of oxide of antimony, so this might set a certain portion of iron free which the carbon and hydrogen of the flame would leave in a very magnetic state (2608)

2574 In further elucidation of the mutual action of the bismuth and the magnet, the bismuth was suspended, as already described (2551), on the bifilar balance, but so turned, that its magnecrystallic axis being horizontal, was not parallel or perpendicular to the arm of the lever, but a little inclined, as in the Figure (5),

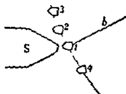


Fig 5

where 1 represents the crystal of bismuth attached to the balance arm *b*, the axis of which is so placed that the crystal can swing through the various positions 1, 2, 3, 4, S is the pole of the magnet separated only by the glass of the shade It is manifest, that in position 1 the magnecrystallic axes and the lines of magnetic force are parallel to each other, whereas in the positions 2, 3, 4, they are oblique When the apparatus was so arranged that the crystal of bismuth rested at 1, the superinduction of the full magnetic force sent it towards 4, a result of diamagnetic action When however the bismuth had its place of rest at 2, the development of the magnetic force did not make it pass towards 3, in accordance with the former result, but towards 1, which it usually attained and often passed, going a little towards 4 In this case the magnecrystallic and the diamagnetic forces were opposed to each other, and the former gained the advantage up to pos

2575 But though the crystal of bi these cases moves ac lines of the magnetic field, it expec

so in a field where the lines are parallel and of equal force, as between flat faced poles, the crystal being restrained so as to move only parallel to itself, for under such circumstances the forces are equal in both directions and on both sides of the mass, and the only tendency the crystal has, in relation to its magnecrystallic condition, is to turn round a vertical axis until it is in its natural position in the magnetic field

2576 A most important question next arises in relation to the magnecrystallic force, namely whether it is an original force inherent in the crystal of bismuth, &c, or whether it is induced under the magnetic and electric influences When a piece of soft iron is held in the vicinity of a magnet it acquires new powers and properties some persons assume this to depend upon the development by induction of a new force in the iron and its particles, like in nature to that in the inducing magnet by others it is considered that the force originally existed in the particles of the iron, and that the inductive action consisted only in the arrangement of all the elementary forces in one general direction Applying this to the crystal of bismuth, we cannot make use of the latter supposition in the same manner for all the particles are arranged beforehand, and it is that very arrangement of them and their forces which gives the bismuth its power If the particles of a substance be in the heterogeneous condition possessed by those of the iron in its unmagnetic state, then the magnetic force may develop the magnetic, and also the diamagnetic condition, which probably is a condition of induction but it does not appear at once, that it can develop a state of the kind now under consideration

2577 That the particles hold their own to a great extent in all the results is manifest, by the consideration that they have an inherent *power or force, the crystalline force, which is* so unchangeable that no treatment to which they can be subjected can alter it, that it is this very force which, placing the particles in a regular position in the mass, enables them to act jointly on the magnet or the electric current, and affect or be affected by them, and that if the particles are not so arranged, but are in all directions in the mass, then the sum of their forces externally is nothing, and no inductive exertion of the magnet or current can develop the slightest trace of the phenomena

2578 And that particles even before crystallization can act in some degree at a distance, by virtue of their crystallizing force, is, I think, shown by the following fact A jar containing about a quart of solution of sulphate of soda, of such strength as to crystallize when cold by the touch of a crystal of the salt or an extraneous body, was left accidentally, for a week or more unattended to and undisturbed The solution remained fluid but on the jar being touched, crystallization took place throughout the whole mass at once, producing clear, distinct, transparent plates, which were an inch or more in length, up to half an inch in breadth, and very thin, perhaps about the one fiftieth or one-sixtieth of an inch These were all horizontal, and of course parallel to each other, and I think, if I remember rightly, had their length in the same direction and they were alike in character, and, apparently, in quantity in every part of the jar They almost held the fluid in its place when the jar was tilted, and when the liquid was poured off presented a beautiful and uniform assemblage of crystals The result persuaded me, at the time, that though the influence of a particle in solution and about to crystallize must be immediately and essentially upon its neighbours, yet that it could exert an influence beyond these, without which influence the whole mass of solution could hardly have been brought into such a uniform crystallizing state Whether the horizontality of the plates can have any relation to the almost vertical lines of magnetic force, which from the earth s magnetism was pervading the solution during the whole time of its rest, is more than I will venture to say

2579 The following are considerations which bear upon this great question (2576) of an original or an induced state

2580 In the first place, the bismuth carries off no power or particular state from the magnetic field, able to make it affect a magnet (2504), so that if the condition acquired by the *crystal be an induced condition, it is probably* a transient one, and continues only whilst under induction The fact therefore, though negative in its evidence, agrees, as far as it tells, with that supposition

2581 In the next place, if the effect were wholly due, as far as the crystal is concerned, to an original power inherent in the mass, we might expect to find the earth's magnetism or any weak magnet, affecting the crystal It is true that a weak magnetic force ought to *induce* any given condition in a crystal of bismuth just as well as a stronger, only proportionally But if the given condition were inher-

ent in the crystal, and did not change in its amount by the degree of magnetic force to

gument, I was induced to repeat the experiment of the earth's influence (2505) very carefully, and by sheltering the suspended crystals in small flasks or jars contained within the larger covering jar, and making the experiment in an underground place of uniform and constant temperature, I was able to exclude every effect of currents of air, so that the crystals obeyed the slightest degree of torsion given to the suspending fibre by the index above Under these circumstances I could obtain no indications of pointing by the earth's action, either with crystals of bismuth or of sulphate of iron Perhaps at the equator, where the lines of force are horizontal, they might be rendered sensible

2582 In the third place, assuming that there is an original force in the crystals and their molecules, it might be expected that they would show some direct influence upon each other,

But on placing a large crystal with its magnecrystallic axis horizontal under a smaller and suspended one, or side by side with it, I could procure no signs of mutual action, even when the approximated parts of the crystals were ground or dissolved away, so as to let the two masses come as near as possible to each other, having large surfaces at the smallest possible distance Extreme care is required in such ex-

2583 Neither could I find any trace of mutual action between crystals of bismuth, or of sulphate of iron, when they were both in the *magnetic field*, the one being freely suspended and the other brought in various positions near to it

2584 From the absence therefore or extreme weakness of any power in the crystals to affect each other, and also from the action of heat which can take away the power of the crystal before it has lost its mere crystalline condition (2570), I am induced to believe that the force manifested in the crystal when in the magnetic

field which appears by external

tion

2585 In that case the word *magnetocrystallic* ought probably to be applied to this force, as it is generated or developed under the influence of the magnet The word *magnecrystallic* I used purposely to indicate that which I believed belonged to the crystal itself, and I shall still speak of the magnecrystallic axis, &c , in that sense

2586 This force appears to me to be very strange and striking in its character It is not polar, for there is no attraction or repulsion Then what is the nature of the mechanical force which turns the crystal round (2460), or makes it affect a magnet (2564)? It is not like a turning helix of wire acted on by the lines of magnetic force, for there, there is a current of electricity required, and the ring has polarity all the time and is powerfully attracted or repelled[1]

2587. If we suppose for a moment that the axial position is that in which the crystal is unaffected, and that it is in the oblique position that the magnecrystallic axial direction is affected and rendered polar, giving two tensions pulling the crystal round, then there ought to be attractions at these times, and an obliquely presented crystal ought to be attracted by a

netic force (2552), which it does not do

2589 I do not remember heretofore such a case of force as the present one, where a body is brought into position only, without attraction or repulsion

[1] Perhaps these points may find their explication hereafter in the action of contiguous particles (1663, 1710, 1729, 1735 2443)

2590 *If the power be induced, it must be* like, generally, to its inducing predominants, and these are, at present, the magnetic and electric forces If induced, subject to the crystalline force (2577), it must show an intimate relation between it and them How hopeful we may be, therefore, that the results will help to throw open the doors which may lead us to a full knowledge of these powers (2146), and the combined manner in which they dwell in the particles of matter and exert their influence in producing the wonderful phenomena which they present!

2591 *I cannot resist throwing forth another* view of these phenomena which may possibly be the true one The lines of magnetic force may perhaps be assumed as in some degree resembling the rays of light heat, &c , and may find difficulty in passing through bodies, and so be affected by them, as light is affected They may, for instance, when a crystalline body is interposed pass more freely, or with *less disturbance through it in the direction of* the magnecrystallic axis than in other directions In that case the position which the crystal takes in the magnetic field with its magnecrystallic axis *parallel* to the lines of magnetic force, may be the position of no or of least resistance and therefore the position of rest and *stable equilibrium All* the diametral effects would agree with this view Then just as the optic axis is *to* a ray of polarized light namely, the direction in which it is not affected so would the magnecrystallic axis be to the lines of magnetic force If such were the case, then, also, as the phenomena *are developed in crystalline* bodies, we might hope for the discovery of a series of effects dependent upon retardation and influence in direction, parallel to the beautiful phenomena presented by light with similar bodies In making this supposition, I do not forget the points of inertia and momentum but such an idea as I can form of inertia does not exclude the above view as altogether *irrational I remember too*, that, *when a mag*netic pole and a wire carrying an electric current are fastened together, so that one cannot turn without the other, if the one be made axis the other will revolve round and carry the first with it, and also, that if a magnet be floated in mercury and a current sent down it, the magnet will revolve by the powers which are *within* its mass With my imperfect mathe*matical knowledge, there seems as much dif*ficulty in these motions as in the one I am supposing and therefore I venture to put forth the idea[1] The hope of a *polarized* bundle of magnetic forces is enough of itself to make one work earnestly with such an object, though only in imagination, before us, and I may well say that no man, if he take industry, impartiality and caution with him in his investigations of science, ever works experimentally in vain

2592 I have already referred, in the former paper (2469), to Plucker s beautiful discovery and results in reference to the *repulsion of the* optic axis[2] of certain crystals by the magnet, and have distinguished them from my own obtained with bismuth, antimony and arsenic, which are *not cases of either repulsion or at*traction believing then with Plucker, that the force there *manifested* is an optic axis force, exerted in the equatorial direction, and therefore existing in a direction at right angles to that which produces the magnecrystallic phenomena

2593 But the relations of *both* to crystalline structure and therefore to the force which con*fers that condition* are most evident *Other* considerations as to position, set, and turning, also show that the two forces, so to say, have a very different relation to each other to that which exists between them and the magnetic or diamagnetic force. As, therefore, this strong likeness on the one hand, and distinct separation on the other are clearly indicated, I will endeavour to compare the two sets of effects, with the view of ascertaining whether the *force* exerted in producing them is not identical

2594 I had the advantage of verifying Plucker's results under his own personal tuition in *respect of tourmaline, staurolite, red ferro-prus*siate of potassa, and Iceland spar Since then, and in reference to the present inquiry, I have carefully examined calcareous spar, as being that one of the bodies which was at the same time free from magnetic action and so simple in its crystalline relations as to possess but one optic axis

2595 When a small rhomboid, about 0 3 of an *inch in its greatest dimension, is suspended,* with its optic axis horizontal, between the pointed poles (2458) of the electro-magnet, approximated as closely as they can be to allow *free motion*, the rhomboid sets in the equatorial direction and the optic axis coincides with the magnetic axis but, when the poles were separated to the distance of half, *or* three-quarters of an

[1] See *note* (2639)

[2] On the Repulsion of the Optic Axes of Crystals by the Poles of a Magnet Poggendorff s *Annalen*, Vol LXXII October 1847 or Taylor s *Scientific Memoirs* Vol. V, p 353

inch the rhomboid turned through 90°, and set with the optic axis in the equatorial direction and the greatest length axial In the first instance the diamagnetic force overcame the optic axis force in the second the optic axis

tion in which its optic axis was equatorial

2597 I also took three cubes of calcareous spar (1695) in which the optic axes were perpendicular to two of the faces of the respec-

poles In all cases the optic axis if horizontal passed into the equatorial position or if vertical left the cubes indifferent as to direction It was easy by the method of two positions (2470) to find the line of force which being vertical left the mass unaffected by the magnet or being horizontal went into the equatorial position and then examining the cube by polarized light it was found that this line coincided with the optic axis

2598 Even the horseshoe magnet (2485) is sufficiently strong to produce these effects

2599 I tried two similar cubes of rock crys

2600

ently leaves an imperfect idea on my mind and a thought that there is some other effect or residual phenomena to be recognized and accounted for

2601 On further consideration it appears that a simple combination of the magnecrystalline condition *as it exists in* bismuth will supply us with a perfect representation of the state of calcareous spar for by placing two equal pieces of bismuth with their magnecrystallic axes perpendicular to each other (2484) we have a system of forces which seems to possess as a resultant a line setting in the equatorial direction When that line is vertical the *system is as regards position indifferent* but when horizontal the system so stands that the line is in the equatorial plane Still the real force is not in the equatorial direction but axial and the system is moved by what may be considered a *plane of axial force* (resulting from the union of the two axes at right angles to each other) rather than by a *line of equatorial force*

2602 Doubtless the rhomboid or cube (2597) of calcareous spar is not a compound crystal like the system of bismuth crystals just referred

does not seem to me to be any way consistent with the cleavage of the substances in three or more directions

mechanical means of observing cohesion a piece

sidered, for in calcareous spar it does not coincide with either the axial or the equatorial direction of the substance in the magnetic field we must endeavour to look beyond this to the polar (or axial) condition of the particles of the masses, for the full understanding and true relation of all these points

2605 I am bound, also, to admit that, if we *consider calcareous spar as giving the simple* system of force, we may, by the juxtaposition of two crystals with their optic axes at right angles to each other, produce a compound mass, which will truly represent the bismuth in the direction of the force i e , it will, in the magnetic field, point with *apparently one line of* force only, and that in the axial direction, whilst it may be really *moved by a system of forces* lying in the equatorial plane I will not at present *pretend to say that this is not the state of* things, but I think, however, that the metals, *bismuth, antimony and arsenic, present us* with the simplest as they do the strongest cases of *magnecrystallic force, and whether that be so* or not, I am still of opinion that the phenomena discovered by Plücker and those of which I have given an account in these two papers, have one common origin and cause

2606 I went through all the experiments and reasonings with Plucker's crystals (as the carbonate of lime, tourmaline and red ferroprussiate of potassa), in reference to the question of *original* or induced power (2576), as before, and came to the same conclusion as in the former case (2584)

2607 I could not find that crystals of red ferro-prussiate of potassa or tourmaline were affected by the earth's magnetism (2581), or that they had the power of affecting each other (2582) Neither could I find that Plucker's effect with calcareous spar, or red ferro-prussiate of potassa, was either an attractive or repulsive effect, but one connected with position only (2550, 2560) All which circumstances tend to convince me that the force active in his experiments, and that in my results with bismuth, &c , is the same [1]

2608 A small rhomboid of Iceland spar was raised *to the highest temperature in the magnetic field* which a spirit-lamp could give (2570), it was at least equal to the full red heat of copper, but it pointed as well then as before A *short thick tourmaline was heated to the same* degree, and it also pointed equally well As it cooled, however, it became *highly* magnetic, and seemed to be entirely useless for experiments at low temperatures, but on digesting it for a few seconds in nitromuriatic acid, a little *iron was dissolved from the surface, after which* it pointed as well, and in accordance with Plucker's law, as before A little peroxide upon the surface had been reduced by the flame and heat to protoxide, and caused the magnetic appearances

2609 There is a general and, as it appears to me, *important relation between Plucker's* magneto-optical results and those I formerly obtained *with heavy glass and other bodies* (2152, &c) When any of these bodies is subject to *strong induction under the influence of the* magnetic or electric forces, it acquires a peculiar *state, in which it can influence a polarized* ray of light The effect is a rotation of the *ray, if it be passed through the substance parallel* to the lines of magnetic force, or in other words, in the axial direction, but if it be passed in the equatorial direction, no effect is produced The equatorial plane, therefore, is that plane in which the condition of the molecular forces is the least disturbed as respects their influence *on light So also in Plucker's results, the optic* axis, or the optic axes, if there be two, go into that plane under the same magnetic influence, they also being the lines in which there is the least, or no action on polarized light

2610 If a piece of heavy glass, or a portion of water, could be brought beforehand into this constrained condition, and then placed in the magnetic field, I think there can be no doubt that it would move, if allowed to do so, and place itself naturally, so that the plane of no action on light should be equatorial, just as Plücker shows that a crystal of calcareous spar or tourmaline does in his experiments And, as *in his case, the magnetic or diamagnetic* character of the bodies, makes no difference in the *general result, so in my experiments, the* optical effect is produced in the same direction, and *subject to the same laws, with both classes of* substances (2185, 2187)

2611 But though thus generally alike in this great and leading point, there is still a vast difference in the disposition of the forces in the heavy glass and the crystal, and there is a still greater difference in this, that the heavy glass

[1] The optic axis is the direction of least optic force, and by Plucker's experiments coincides with what I consider in my results as the direction of minimum magnecrystallic force It is more than probable that wherever the two sets of effects (whether really or only nominally different) can be recognized in the same body, the directions of maximum effect and also those *of minimum effect will be found to coincide* November 23, 1848

takes up its state only for a time by constraint and under induction, whilst the crystal possesses it freely, naturally and permanently In both cases, however, whether natural or induced, it is a state of the particles and comparing the effect on light of the glass under constraint with that of the crystal at liberty, it indicates a power in the magnet of inducing something like that condition in the particles of matter which is necessary for crystallization, and that even in the particles of fluids (2184)

2612 If there be any weight in these considerations, and if the forces manifested in the crystals of bismuth and Iceland spar be the same (2607), then there is further reason for believing that in the case of bismuth and the other metals named, there is, when they are subjected to the power of the magnet, both an induced condition of force (2584), and also a pre-existing force (2577) The latter may be distinguished as the crystalline force, and is shown, first, by such bodies exhibiting optic axes and lines of force when not under induction by the symmetric condition of the whole mass, produced under circumstances of ordinary occurrence, and by the fixity of the line of magnecrystallic force in the bodies shown experimentally to possess it

2613 Though I have spoken of the magnecrystallic axis as a given line or direction yet I would not wish to be understood as supposing that the force decreases, or state changes, in an equal ratio all round from it It is more probable that the variation is different in degree in different directions, dependent on the powers which give difference of form to the crystals The knowledge of the disposition of the force can be ascertained minutely hereafter, by the

(2500, 2530)

2614 I cannot conclude this series of *Researches* without remarking how rapidly the knowledge of molecular forces grows upon us, and how strikingly every investigation tends to develop more and more their importance, and their extreme attraction as an object of

through it, with the forces concerned in cohesion, and we may, in the present state of things, well feel urged to continue in our labours encouraged by the hope of bringing it into a bond of union with gravity itself

Royal Institution October 20 1848

¶ vi Note *On the Position of a Crystal of Sulphate of Iron in the Magnetic Field*

Received December 7, 1848, Read December 7, 1848

2615 Though effects of the following nature are general yet I think it convenient to state that I obtained them chiefly by the use of magnetic poles (2247), the form of which is given in the plan and side view annexed (*Fig 6*) The

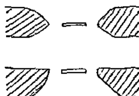


Fig 6

crystals submitted to their action were suspended by cocoon silk so as to be level with the upper surface of the poles

2 25 inches, the prism assumed an oblique posi-

tion (2634), more or less inclined to the axial line, and so passing gradually from the one position to the other This intermediate distance I will for the present call *n* (neutral) distance

2617 If the poles be 2 inches apart and the crystal be gradually lowered it passes through the same intermediate oblique positions into the transverse position or if the crystal be raised, the same transitions occur at any less distance the changes are the same, but later *They occur more rapidly when the crystal is* raised than when it is lowered but this is only because of the unsymmetric disposition and intensity of the lines of magnetic force around the magnetic axis, due to the horseshoe form of the magnet and shape of the poles If two cylinder magnets with equal conical terminations were employed there is no doubt that for equal amounts of elevation or depression, corresponding changes would take place in the position of the crystal

2618 These changes however are not due to *mere diminution of the magnetic force by distance* but to differences in the *forms* or *direction* of the resultants of force This is shown by the fact that, if the crystal be left in its first position and so pointing with the length axially, no diminution of the force of the magnet alters the position thus, whether one or ten pair of *plates be used to excite the magnet, the n distance* (2616) remains unchanged and even descending to the use of an ordinary horseshoe magnet, I have found the same result

2619 Variation in the length of the prismatic crystal has an important influence over the result As the crystal is shorter, the distance *n* diminishes, *all the other phenomena remaining* the same. A crystal 0 7 of an inch long, but *thicker than the last, had for its maximum n* distance 1 7 inch A still shorter crystal had for its maximum *n* distance 1 1 inch In all these cases variation of the force of the magnet caused *no sensible change*

2620 *Variation in that dimension of the crys*tal coincident with the magnecrystallic axis affected the *n* distance thus, increase in the length of the magnecrystallic axis diminished the distance, and diminution of it in that direction increased the distance This was shown in two ways, first, by placing a second prismatic *crystal by the side of the former in a symmetric* position (2636), which reduced the *n* distance to between 1 75 and 2 inches, and next, by employing two crystals in succession of the same length but different thicknesses The thicker one had the smaller *n* distance

2621 Variation in *the depth of the crystal*, i e its vertical dimension, did not produce any sensible effect on the *n* distance nor by theory should it do so, until the extension upwards or downwards brings the upper or lower parts into *the condition of raised or depressed portions* (2617)

2622 Variation in the form of the poles affects the *n* distance As they are more acute, the distance increases, and as they are more *obtuse up to flat-faced poles (2463), the dis*tance diminishes

2623 With the shorter crystals, or with obtuse poles it is often necessary to diminish the power of the magnet or else the crystal is liable to be drawn to the one or other pole This, however, may be avoided by employing a vertical *axis which is confined below as well as* above (2554) and then the difference in *strength* of the magnet is shown to be indifferent to the results, or very nearly so

2624 These effects *may probably* be due to the essential difference which exists between the ordinary magnetic and the magnecrystallic action, in that the first is *polar*, and the second only *axial* (2472) in character If a piece of magnetic matter iron for instance, be in the magnetic field, it immediately becomes polar (*i e*, has *terminations of different qualities*) If many iron particles be there, they all become polar and if they be free to move, arrange themselves in the direction of the axial line, being joined to each other by contrary poles, and by that the polarity of the extreme particles is increased Now this does not appear to be at *all the case with particles under the influence* of the magnecrystallic force the force seems to be altogether *axial*, and hence probably *the* difference above, and in many other results

2625 Thus, if four or more little cubes *of* iron be suspended in a magnetic field of equal *force (2465), they will become polar, if* also *four similar cubes of crystallized* bismuth be similarly circumstanced, they will be affected and point *If the iron cubes be arranged together* in the direction of the equatorial line, they will form an aggregate in a position of unstable equilibrium, and will immediately, as a whole, turn and point with the length axially, whereas the bismuth cubes by such approximation will suffer no sensible change

2626 *The extreme (and the other) associated* cubes of the elongated iron arrangement now have a polar force above that which *they had* before, and the whole group serves, as it were,

as a conductor for the lines of magnetic power for many of them concentrate upon the iron and the intensity of power is much stronger between the ends of the iron arrangement and the magnetic poles than it is in other parts of the magnetic field Such is not the case with the bismuth cubes for however they be ar

molecules of the crystals appears to remain the same Hence the iron stands lengthways between the poles the bismuth crystals on the contrary whethe arrang d lo h do as so

intens ty of the field producing a pointed form of pole in one part with diverging lines of force a crystal of bismuth vibrates with sens bly equal force in every part of the field (2467) and does not d

time magnetic and magnecrystallic may be traced to that which causes them and their dif fe

the magnetic force so much better than it was conducted in the san e space before that the lines of force between the ends of this bar and the magnetic poles will be concentrated and made more intense than anywhere else in the magnetic field If the poles be made to approach towards the bar this effect will increase and the bar will cond ict more and more of the magnetic force and point with proportionate intens ty It is not merely that the magnetic field becomes more intense by the approximation of the poles but the proportion of force carrie l on by the bar becomes greater as com

power does not rise in the same manner or in the same great proportion by approximation of the poles There can be no doubt that such approximation increases the intensity of the lines of force and therefore increases the inten s ty of the magneto crystallic state but this

rapid degree as the directive force of the magnetic bar just referred to

2630 If then we take a bar which like a

grows up more rapidly and din inishes more rap dly than the magneto-crystall c force

2631 This view also is consistent with the fact that variation of the force of the magnet

an l their proportion therefore remains the same

263? The raising or lowering of the crystal above or below the line of maximum magnetic force is manifestly equivalent in principle to

felt here

2633 M Plücker told me when in England in August last that the repulsive force on tl e optic axis diminishes and increases less rapidly

than the magnetic force, by change of distance, but is not altered in its proportion to the magnetic force by employing a stronger or weaker magnet This is manifestly the same effect as that I have been describing, and makes me still more thoroughly persuaded that his results and mine are due to one and the same cause (2605, 2607)

2634 I have said that, within the *n* distance, the crystal of sulphate of iron pointed more or less obliquely (2616), I will now state more particularly what the circumstances are. If the distance *n* be so adjusted, that the prismatic crystal, which is at the time between the magnetic poles, shall make an angle of 30° (or any quantity) with the axial line, then it will be found that there is another stable position, namely, the diametral position (2461), in which it can stand, but that the obliquity is always on the same side of the axial line and that the crystal will not stand with the like obliquity of 30° on the opposite side of the magnetic axis

2635 If the crystal be turned 180° round a vertical axis, or end for end, then the inclination, and the direction in which it occurs, remain unchanged, in fact, it is simply giving the crystal the diametral position But if the crystal be revolved 180° round a horizontal axis, either that coinciding with its length, which represents its maximum magnetic direction, or that corresponding with its breadth, and therefore with the magnecrystallic axis, then the inclination is the same in amount as before, but it is on the *other* side of the axial line

2636 This is the case with all the prismatic crystals of sulphate of iron which I have tried The effect is very determinate, and, as would be expected, when two crystals correspond in the direction of the inclination, they also correspond in the position of their form and direction of the various planes

2637 All these variations of *position* indicate an oblique resultant of setting force, derived from the joint action of the magnetic and magnecrystallic forces, and would be explained by the supposition that the magnecrystallic axis or line of maximum magnecrystallic force was not perpendicular to the chief planes of the crystal (or those terminating it), but a little inclined in the direction of the length

2638 Whether this be the case, or whether the maximum line of magnetic force may not, even, be a little inclined to the length of the prism, still, the *n* distance supplies an excellent experimental opportunity of examining this inclination, however small its quantity may be, because of the facility with which the influence of either the one or the other may be made predominant in any required degree

Royal Institution, December 5, 1848

2639 *Note* (2591) Another supposition may be thrown out for consideration I have already said that the assumption of a mere axial condition (2587, 2591) would account for the set without attraction or repulsion Now if we suppose it possible that the molecules should become polar in relation to the north and south poles of the magnet, but with *no mutual relation amongst themselves*, then the bismuth or other crystal might set as if induced with mere axial power but it seems to me very improbable that polarities of a given particle in a crystal should be subject to the influence of the polarities of the distant magnet poles, and not also to the *like polarities* of the contiguous particles —*January 24, 1849*

TWENTY-THIRD SERIES[1]

§ 29. *On the Polar or Other Condition of Diamagnetic Bodies*

RECEIVED JANUARY 1, READ MARCH 7 AND 14, 1850

2640 FOUR years ago I suggested that all the phenomena presented by diamagnetic bodies, when subjected to the forces in the magnetic field, might be accounted for by assuming that they then possessed a polarity the same in kind as, but the reverse in direction of, that acquired by iron, nickel and ordinary magnetic bodies under the same circumstances (2429, 2430) This view was received so favourably by Plücker, Reich and others, and above all by W. Weber,[2] that I had great hopes it would be confirmed,

[1] *Philosophical Transactions* 1850 p 171

[2] Poggendorff's *Annalen*, January 7, 1848 or Taylor's *Scientific Memoirs*, V, p 477

and though certain experiments of my own (2497) did not increase that hope still my desire and expectation were in that direction

2641 Whether bismuth copper phosphorus &c when in the magnetic field are polar or not is however an exceedingly important question and very essential and great differences in the mode of action of these bodies under the one view or the other must be conceived to exist I found that in every endeavour to proceed by induction of experiment from that which is known in this department of science to the unknown so much uncertainty hesitation and discomfort arose from the unsettled state of my mind on this point that I determined if

philosophical paper and so important do I think it for the progress of science that in those imperfectly developed regions of knowledge which form its boundaries our conclusions and ded ictions should not go far beyond or at all events not aside from the results of ex

Royal Society

2642 It appeared to me that many of the results which had been supposed to *indicate* a

these modes of action and that of a real polarity whether magnetic or diamagnetic might serve as a foundation on which to base a mode

polarity exists it must be in the particles and for the time permanent and therefore distinguishable from the momentary polarity of the mass due to induced temporary currents and

of a crank and wheel made to vibrate in a horizontal plane so that its free extremity passed

ter were fixed in succession to the end of a brass rod 2 feet long which itself was attached

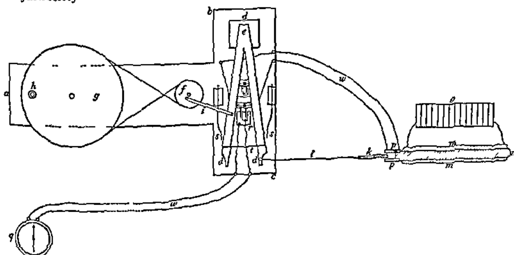


Fig 1

at the other end to the mov... f
the lever ...

... cylinder electro-
... was also prepared (2191), the iron core of which was 21 inches long, and 1 7 inch in diameter, but one end of this core was made smaller for the length of 1 inch, being in that part only 1 inch in diameter

2644 On to this reduced part was fixed a hollow helix consisting of 516 feet of fine covered copper wire it was 3 inches long, 2 inches external diameter, and 1 inch internal diameter when in its place, 1 inch of the central space was occupied by the reduced end of the electro-magnet core which ...
magnet ...

... and
... the latter, in its motion, would move within the helix in the direction of its axis, approaching to and receding from the electro-magnet in rapid or slow ...
least and great ...
in...
on ... the ob-
jec... to observe any influence upon the experimental helix of fine wire which the metal cylinders might exert, either whilst moving to or from the magnet, or at different distances from it [1]

2645 The extremities of the experimental helix wire were connected with a very delicate galvanometer, placed 18 or 20 feet from the machine, so as to be unaffected directly by the electro-magnet but a commutator was interposed between them This commutator was moved by the wooden lever (2643), and as the electric currents which would arrive at it from the experimental helix, in a *complete cycle* of motion or to and fro action of the metal cylinder (2643), would consist of two contrary portions, so the office of this commutator was, sometimes to take up these portions in succession and send them on in one consistent current to the galvanometer, and at other times to oppose them and to neutralize their result, and therefore it was made adjustable, so as to change at any period of the time or part of the motion

2646 With such an arrangement as this it is known that, however powerful the magnet, and however delicate the other parts of the apparatus, no effect will be produced at the galvanometer as long as the magnet does not change in force, or in its action upon neighbouring bodies, or in its distance from, or relation to, the experimental helix, but the introduction of a piece of iron into the helix, or anything else that can influence or be influenced by the magnet, can, or ought to, show a corresponding influence upon the helix and galvanometer My apparatus I should imagine, indeed, to be almost the same in principle and practice as that of M Weber (2640), except that it gives me contrary results

2647 But to obtain correct conclusions, it is most essential that extreme precaution should be taken in relation to many points which at first may seem unimportant ...
appara... ...
be fixe...
nomica... any motion of any portion of it is, from the construction, sure to synchronize with the motion of ...
tor and nort...
are
whol...
care,
resul...
mach... magnet and helix, and the galvanometer stood upon separate tables, and these again upon a stone floor laid upon the earth, and the table carrying the machine was carefully strutted to neighbouring stonework

2648 Again, the apparatus should itself be perfectly firm and without shake *in its motion* and yet easy and free No iron should be employed in any of the moving parts I have springs to receive and convert a portion of the momentum of the whole at the end of the to and fro journey, but it is essential that these should be of hammered brass or copper

2649 It is absolutely necessary that the cylinder or core in its motion should not in the least degree disturb or shake the experimental helix and the magnet Such a shake may *easily* take place and yet (without much experience) not be perceived It is important to have the cores of such bodies as bismuth, phosphorus, copper, &c , as large as may be, but I have not found it safe to have less than one-eighth of an inch of space between them and the interior of the experimental helix In order to float, as it were, the core in the air, it is convenient to suspend it in the bight or turn of a fine copper wire passing once round it, the ends of which rise up, and are made fast to two fixed points at equal heights but wide apart, so that the

[1] It is very probable that if the metals were made into cylinders shorter, but of larger diameter than those described above, and used with a corresponding wider helix, better results than those I have obtained would be acquired.

wire has a V form This suspension keeps the core parallel to itself in every part of its motion

2650 The magnet, when excited, is urged by an electric current from five pairs of Grove's plates, and is then very powerful When the battery is not connected with it, it still remains a magnet of feeble power, and when thus employed may be referred to as in the *residual state* If employed in the residual state, its power may for the time be considered constant, and the experimental hel [illegible]

[illegible]

ute or more, and which has the appearance of being derived at once from that of the battery. [illegible]

[illegible]

[illegible] has been out of use When first employed, after two or three days' rest, it will amount to eighty or ninety seconds, or more On breaking battery contact and immediately renewing it, the effect will be repeated, but occupy only twenty or thirty seconds On a third intermission and renewal of the current, it will appear for a still shorter period, and when the magnet has been used at short intervals for some time, it seems capable of receiving its maximum power almost at once In every experiment it is necessary to wait until the effect is shown by the galvanometer to be over, otherwise the last remains of such an effect might be mistaken for a result of polarity, or some peculiar action of the bismuth or other body under investigation

2651. The galvanometer employed was made by Ruhmkorff and was very sensible The needles were strengthened in their action and rendered so nearly equal that a single vibration to the right or to the left occupied from sixteen to [illegible]

cuit was continually ascertained by a feeble thermo-electric pair, warmed by the fingers. This was done also for every position of the commutator, where the film of oxide formed on any part by two or three days' rest was quite sufficient to intercept a feeble current

2652. In order to bring the phenomena afforded by magnetic and diamagnetic bodies into direct relation, I have not so much noted the currents produced in the experimental helix, as the effects obtained at the galvanometer. It is to be understood, that the standard of *deviation, as to direction, has always been that* produced by an iron wire moving in the same direction at the experimental helix, and with the same condition of the commutator and connecting wires, as the piece of bismuth or other body whose effects were to be observed and compared

2653 A thin glass tube, of the given size (2643), 5½ by ¾ inches, was filled with a saturated solution of protosulphate of iron, and employed as the experimental core the velocity given to the machine at this and all average times of experiment was such as to cause five or six approaches and withdrawals of the core in one second, yet the solution produced no sensible indication at the galvanometer A piece [illegible]

[illegible]

of iron caused the needle to move about 2°, and cores formed out of single large crystals, or symmetric groups of crystals of sulphate of iron, produced the same effect Red oxide of iron (colcothar) produced the least possible ef- [illegible]

deficiency of power in that respect does not interfere with its ability to search into the nature of the phenomena that appear in the experiments of Weber, Reich and others

[illegible]

the contrary direction, and for some of the metals, as copper, silver and gold, it amounted to 60° or 70°, which was permanently sustained as long as the machine continued to work. But the deflection was not the greatest for the most diamagnetic substances as bismuth or antimony, or phosphorus on the contrary, I have not been able to assure myself, up to this time, that these three bodies can produce any effect Thus far the effect has been proportionate to the *conducting power* of the substance for electricity Gold silver and copper have produced large deflections lead and tin less Platina very little Bismuth and antimony none

2656 Hence there was every reason to believe that the effects were produced by the currents induced in the mass of the moving metals, and not by any polarity of their particles I proceeded therefore to test this idea by different conditions of the cores and the apparatus

2657 In the first place if produced by induced currents, the great proportion of these would exist in the part of the core near to the dominant *magnet*, and but little in the more distant parts whereas in a substance like iron, the polarity which the whole assumes makes length a more important element I therefore shortened the core of copper from 5½ inches (2643) to 2 inches, and found the effect not sensibly diminished, even when 1 inch long it was little less than before On the contrary, when a fine iron wire 5½ inches in length was used as core its effects were strong, when the length was reduced to 2 inches, they were greatly diminished, and again, with a length of 1 inch, still further greatly reduced It is not difficult to construct a core of copper, with a fine [illegible] wire in its axis, so that [illegible] length [illegible]

[illegible] effect were p[illegible] [ind]uced currents in the mass (2642), division of the mass would stop these currents and so alter the effect, whereas if produced by a true diamagnetic polarity, division of the mass would not affect the polarity seriously, or in its essential nature (2430) Some copper filings were *therefore* digested for a few days in dilute sulphuric acid to remove any adhering iron, then well washed and dried, and afterwards warmed and stirred in the air, until it was seen by the orange colour that a very thin film of oxide had formed upon the[illegible] finally intro[illegible] employe[illegible] ever, but [illegible]

2659 The copper may however be divided so as either *to interfere* with the assumed currents or not, at pleasure Fine copper wire was cut up into lengths of 5½ inches, and as many of these associated together as would form a compact cylinder three-quarters of an inch in diameter (2643) it produced no effect at the galvanometer Another copper core was prepared by associating together many *discs* of thin copper plate, three-quarters of an inch in diameter, and this affected the galvanometer, holding its needle 25° or 30° from zero

2660 I made a solid helix *cylinder*, three-quarters of an inch in diameter and 2 inches long, of covered copper wire, one-sixteenth of an inch thick and employed this as *the experimental core* When the two ends of its wire were unconnected, there was no effect upon the experimental helix, and *consequently none* at the galvanometer but when the ends were soldered together, the needle was well affected In the first condition the *currents, which tended* to be formed in the mass of moving metal, could not exist because the metal circuit was interrupted in the second they *could, because* the circuit was not interrupted, and such division as remained did not interfere to prevent the currents

2661 The same results were obtained with other metals A core cylinder of gold *made of* half sovereigns, was very powerful in its effect *on the galvanometer* A cylinder of silver, made of sixpenny pieces, was very effectual, but a cylinder made of precipitated silver, pressed into a glass tube as closely as possible, gave no indications of action whatever The same results were obtained with disc cylinders of tin and lead, the effects being proportionate *to the* condition of tin and lead as bad conductors (2655)

2662 When iron was divided, the effects were *exactly* the reverse in kind It was necessary to use a much coarser galvanometer and apparatus for the purpose but *that* being done, the employment of a solid iron core, and of another of the same size or weight formed of lengths of fine iron wire (2659), showed that the division had occasioned no inferiority in the latter The excellent experimental researches of Dove[1] on the electricity of induction, will show that this ought to be the case.

2663 Hence the result of division in the diamagnetic metals is altogether of a nature to confirm the conclusion, that the effects pro-

[1] Taylor's *Scientific Memoirs* V, p. 129 I do not see a date to the paper

duced by them are due to induced currents moving through their masses, and not to any polarity correspondent in its general nature (though opposed in its direction) to that of *iron*

2664 *In the third place (2656)*, another and very important distinction in the actions of a diamagnetic metal may be experimentally established according as they may be due either to a true polarity, or merely to the presence of temporary induced currents, and as for the consideration of this point diamagnetic and magnetic polarity are the same, the point may best be considered, at present, in relation to iron

2665 If a core of any kind be advanced towards the dominant magnet and withdrawn from it by a motion of uniform velocity, then a complete journey, or *to* and *from* action, might be divided into four parts, the *to*, the *stop* after it, the *from*, and the *stop* succeeding that If a core of iron make this journey, its end towards the dominant magnet becomes a pole rising in force until at the nearest distance and falling in force until at the greatest distance Both this effect and its *progression* inwards and outwards, cause currents to be induced in the surrounding helix, and these currents are in one direction as the core advances, and in the contrary direction as it recedes In reality, however,

ually rises from a state of rest to a maximum velocity, which is half way, and then as gradually sinks to rest again near the magnet and the *from* part of the journey undergoes the same variations Now as the maximum effect upon the surrounding experimental helix depends upon the velocity conjointly with the

has greatest magnetic force, but somewhere

forces are changed in place (2429 2430), then the same kind of action as that described for iron would occur with them the only difference being, that the two currents produced would be in the reverse direction to those produced by *iron*

2667 If a commutator, therefore, were to be arranged to gather up these currents, either in the one case or the other, and send them on to

should change at the times of maximum velocity or maximum intensity, or at two other

periment, of this nature If an iron wire be simply introduced or taken out of the experi

an iron wire core, the commutator changing at the stops (2665), then the current gathered up and sent on to the galvanometer is a maximum, if the commutator change at the moments of maximum velocity, or at any other pair of moments equidistant from the one stop or the other, then the current at the commutator is a minimum or 0

2669 There are two or three precautions which are necessary to the production of a pure result of this kind In the first place, the

iron core be at its shortest distance from the dominant magnet at the beginning of the ex-

the *mean or average state*, which it acquires during the continuance of an experiment, and that in rising or falling to this average state, it produces two currents in contrary directions, which are made manifest in the experiments described These existing only for the first moments, do, in their effects at the galvanometer, then appear, producing a vibration which gradually passes away

2670 One other precaution I ought to specify Unless the commutator changes accurately at the given points of the journey, a little effect is gathered up at each change, and may give a permanent deflection of the needle in one direction or the other The tongues of my commutator, being at right angles to the direction of motion and somewhat flexible, dragged a little in the *to* and *from* parts of the journey in doing this they approximated, though only in a small degree, to that which is the best condition of the commutator for gathering up (and not opposing) the currents, and a deflection to the right or left appeared (2677) Upon discovering the cause and stiffening the tongues so as to prevent their flexure, the effect disappeared, and the iron was perfectly inactive

2671 Such therefore are the results with an iron core and such would be the effects with a copper or bismuth core if they acted by a diamagnetic polarity Let us now consider what the consequences would be if a copper or bismuth core were to act by currents, induced for the time, in its moving mass and of the nature of those suspected (2642) If the copper cylinder moved with uniform velocity (2665), then currents would exist in it, parallel to its circumference, during the whole time of its motion, and these would be at their maximum force just before and just after the *to* or inner stop, for then the copper would be in the most intense parts of the magnetic field The rising current of the copper core for the *in* portion of the journey would produce a current in one direction in the experimental helix, the stopping of the copper and consequent falling of its current would produce in the experimental helix a current contrary to the former, the first instant of motion *outwards* in the core would produce a maximum current in it contrary to its former current, and producing in the experimental helix its inductive result, being a current the same as the last there produced, and then, as the core retreated, its current would fall, and in so doing and by its final stop, would produce a fourth current in the experimental helix, in the same direction as the first

2672 The four currents produced in the experimental helix alternate by twos, i e, those produced by the falling of the first current in the core and the rising of the second and contrary current, are in one direction They occur at the instant before and after the stop at the magnet, i e, from the moment of maximum current (in the core) before, to the moment of maximum current after, the stop, and if that stop is momentary, they exist only for that moment, and should during that brief time be gathered up by the commutator Those produced in the experimental helix during the falling of the second current in the core and the rising of a third current (identical with the first) in the return of the core to the magnet, are also the same in direction, and continue from the beginning of the retreat to the end of the advance (or from maximum to maximum) of the core currents, i e, for almost the whole of the core journey and these, by its change at the maximum moments, the commutator should take up and send on to the galvanometer

2673 The motion however of the core is not uniform in velocity, and so, sudden in its change of direction, but, as before said (2665), is at a maximum as respects velocity in the middle of its approach to and retreat from the dominant magnet, and hence a very important advantage For its stop may be said to commence immediately after the occurrence of the maximum velocity, and if the lines of magnetic force were equal in position and power there to what they are nearer to the magnet, the contrary currents in the experimental helix would commence at those points of the journey, but, as the core is entering into a more intense part of the field the current in it still rises though the velocity diminishes and the consequence is, that the maximum current in it neither occurs at the place of greatest velocity, nor of greatest force, but at a point between the two This is true both as regards the approach and the recession of the core, the two maxima of the currents occurring at points equidistant from the place of rest near the dominant magnet

2674 It is therefore at these two points that the commutator should change, if adjusted to produce the greatest effect at the galvanometer by the currents excited in the experimental helix, through the influence of, or in connexion with, currents of induction produced in the core, and experiment fully justifies this conclusion If the length of the journey from the stop out to the stop in, which is 2 inches (2643, 2644), be divided into 100 parts, and the dom-

mint magnet be supposed to be on the right-hand, then such an expression as the following, 50|50, may represent the place where the commutator changes, which in this illustration would be midway in the to and from motion or at the places of greatest velocity

2675 Upon trial of various adjustments of the commutator I have found that from 77|23 to 88|12, gave the best results with a copper core On the whole, and after many experiments I conclude that with the given strength of electro-magnet, distance of the experimental core when at the nearest from the magnet, length of the whole journey, and average velocity of the machine, 86|14 may represent the points where the induced currents in the core are at a maximum and where the commutator ought to change

tion of the polarity, they can be separated and further, they can also be combined in various ways for the purpose of elucidating their joint and separate action

2677 For let the arrows in the diagram represent the to and from journey, and the intersections of the lines, *a b* or *c*, *d*, &c the periods in the journey when the commutator changes

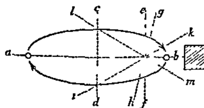


Fig 2

(in which case *c*, *d* will correspond to 50|50, and *e f* to 86|14), then *a*, *b* will represent the condition of the commutator for the maximum effect of iron or any other polar body If the line *a b* be ...

points *c* and *d*, either above or below, that the direction of the deflection will change for iron But the line *a b* indicates those points for the commutator with which no effect will be produced on the galvanometer by the induction of *currents* in the mass of the core If the line be inclined in one direction, as *i*, *k*, then these currents will produce a deflection at the galvanometer on one side if it be inclined in the other direction as *l*, *m*, then the deflection will be on the other side Therefore the effects of these induced currents may be either combined with, or opposed to the effects of a polarity, whether it be magnetic or diamagnetic

2678 All the metals before mentioned (2655), namely, gold silver, copper tin lead, platina, antimony and bismuth were submitted to the power of the electro-magnet under the best adjustment (2675) of the commutator The effects were stronger than before being now at a maximum but in the same order as regarded antimony and bismuth, they were very small, amounting to not more than half a degree, and may very probably have been due to a remain-

percha did not either in this or in the former state of the commutator, give any indication of effect at the galvanometer

2679 As an illustration of the manner in

strong contrary deflections at the needle The

a vibration in less than a second, but with the ... (2675) gives

horizontally between the poles of the electro-magnet, it will go to the equatorial position with a certain force passing, as I have said, from stronger to weaker places of action (2267) If a bar of iron of the same size be fixed in the equatorial position a little below the plain in which the diamagnetic bar is moving the latter will proceed to the equatorial position with much greater force than before, and this is considered as due to the circumstance, that, on the side where the iron has N polarity, the diamagnetic body has S polarity, and that on the other side the S polarity of the iron and the N polarity of the bismuth also coincide

2692 It is however very evident that the lines of magnetic force have been altered sufficiently in their intensity of direction, by the presence of the iron, to account fully for the increased effect For, consider the bar as just leaving the axial position and going to the equatorial position, at the moment of starting its extremities are in places of stronger magnetic force than before, for it cannot be doubted for a moment that the iron bar determines more force from pole to pole of the electro-magnet than if it were away On the other hand, when it has attained the equatorial position, the extremities are under a much weaker magnetic force than they were subject to in the *same places* before for the iron bar determines downwards upon itself much of that force, which, when it is not there, exists in the plane occupied by the bismuth Hence, in passing through 90°, the diamagnetic is urged by a much greater difference of intensity of force when the iron is present than when it is away, and hence, probably, the whole additional result The effect is like many others which I have referred to in magnecrystallic action (2487-2497), and does not, I think, add anything to the experimental proof of diamagnetic polarity

2693 Finally, I am obliged to say that I can find no experimental evidence to support the hypothetical view of diamagnetic polarity (2640), either in my own experiments, or in the repetition of those of Weber, Reich, or others I do not say that such a polarity does not exist, and I should think it possible that Weber, by far more delicate apparatus than mine, had obtained a trace of it, were it not that then also he would have certainly met with the far more powerful effects produced by copper, gold, silver, and the better conducting diamagnetics If bismuth should be found to give any effect, it must be checked and distinguished by reference to the position of the commutator, division of the mass by pulverization, influence of time, &c It appears to me also, that, as the magnetic polarity conferred by iron or nickel in very small quantity, and in unfavourable states, is far more readily indicated by its effect on an astatic needle, or by pointing between the poles of a strong horseshoe magnet, than by any such arrangement as mine or Weber's or Reich's, so diamagnetic polarity would be much more easily distinguished in the same way, and that no indication of that polarity has as yet reached to the force and value of those already given by Brugmann and myself

2694 So, at present, the actions represented or typified by iron by copper and by bismuth, remain distinct and their relations are only in part made known to us It cannot be doubted that a larger and simpler law of action than any we are yet acquainted with, will hereafter be discovered, which shall include all these actions at once and the beauty of Weber's suggestion in this respect was the chief inducement to me to endeavour to establish it

2695 Though from the considerations above expressed (2693) I had little hopes of any useful results, yet I thought it right to submit certain magnecrystallic cores to the action of the apparatus One core was a large group of symmetrically disposed crystals of bismuth (2457), another a very large crystal of red ferroprussiate of potassa, a third a crystal of calcareous spar and a fourth and fifth large crystals of protosulphate of iron These were formed into cylinders of which the first and fourth had the magnecrystallic axes (2479) parallel to the axis of the cylinder, and the second, third and fifth, had the equatorial direction of force (2546 2594, 2595) parallel to the axis of the cylinder None of them gave any effect at the galvanometer, except the fourth and fifth, and these were alike in their results, and were dependent for them on their ordinary magnetic property

2696 Some of the expressions I have used may seem to imply that, when employing the copper and other cores, I imagine that currents are first induced in them by the dominant magnet, and that these induce the currents which are observed in the experimental helix Whether the cores act directly on the experimental helix or indirectly through their influence on the dominant magnet, is a very interesting question, and I have found it difficult to select expressions, though I wished to do so, which should not in some degree prejudge that question It seems to me probable, that the cores

act indirectly on the helix, and that their im mediate action is altogether directed towards the dominant magnet which whether they consist of magnetic or diamagnetic metals raises

are competent to produce the currents in it which are obtained (2653, 2668) As the iron retreats these lines of force diverge and again crossing the line of the wire in the helix in a contrary direction to their former course produce a contrary current It does not seem necessary in viewing the action of the iron core, to suppose any direct action of it on the helix, or any other action than this which it exerts

are produced in it are caused by the direct influence of the magnet and must react equivalently upon it This they do, and because of their direction and known action, they will

and this divergence and convergence of passage in two directions across the wire of the experimental helix is sufficient to produce the two currents which are obtained in the advance of the core towards the dominant magnet (2671,

upon the helix I interposed substances between the core and the helix during the times

wire core (2668) used in the apparatus Still, whatever the form of the experiment, the kind and amount of effect produced were the same as if the copper were away and either glass or air in its place When the dominant magnet was removed and the wire core made a magnet, the same results were produced

silver and copper five-eighths of an inch in thickness employed as before with the best condition of the commutator (2675) the effects with and without the copper or with and without the glass, were absolutely the same (2698)

2700 There can be no doubt that the copper linings when in place were full of currents at the time of action and that when away no

each part acting on every other part, being in what I have occasionally elsewhere imagined as the electro-tonic state (1729)

copper cause them to be resolved into a cur-

Royal Institution, Dec 14, 1849

TWENTY-FOURTH SERIES[1]

§ 30 *On the Possible Relation of Gravity to Electricity*

RECEIVED AUGUST 1, READ NOVEMBER 28, 1850

2702 THE long and constant persuasion that all the forces of nature are mutually dependent, having one common origin, or rather being different manifestations of one fundamental power (2146), has made me often think upon the possibility of establishing, by experiment, *a connexion between gravity and electricity*, and so introducing the former into the group, the chain of which, including also magnetism, chemical force and heat binds so many and such varied exhibitions of force together by common relations Though the researches I have made with this object in view have produced only negative results, yet I think a short statement of the matter as it has presented itself to my mind, and of the result of the experiments, which offering at first much to encourage, *were only reduced to their true value by* most careful searchings after sources of error, may be useful both as a general statement of the problem and as awakening the minds of others to its consideration

2703 In searching for some principle on which an experimental inquiry after the identification or relation of the two forces could be founded, it seemed that if such a relation existed, there must be something in gravity which would correspond to the dual or antithetical nature of the *forms of force in electricity and* magnetism To my mind it appeared possible that the ceding to the force or the approach of gravitating bodies on the one hand and the effectual *reversion of the force or separation of* the bodies on the other, might present the points of correspondence quiescence (as to motion) being the neutral condition The final unchangeability of gravity did not seem affected by such an assumption, for the acting bodies when at rest would ever have the same relation to each other, and it would only be at the times of motion to and fro that any results related to electricity could be expected Such results if possible, could only be exceedingly small but, *if possible, i e, if true, no terms could exag*gerate the value of the relation they would establish

2704 The thought on which the experiments were founded was that as two bodies moved towards each other by the force of gravity, currents of electricity might be developed either *in them or in the surrounding matter in one di*rection, and that as they were by extra force moved from each other against the power of gravitation, the opposite currents might be produced Also that these currents would have relation to the line of approach and recession, and not to space generally, so that two bodies approaching would have currents in the opposite direction as to space generally, but the same as to the direction of their motion along the line joining them It will be unnecessary to *go further into the suppositions which arose* concerning these points, or regarding the effect of forced motions either coinciding with, or across the direction of the earth s gravitation, and many other matters, than to say that as the effect looked for was exceedingly small so no hope was entertained of any result except by means of the gravitation of the earth The earth was therefore made to be the one body, and the indicating mass of matter to be experimented with the other

2705 *First of all* a body, which was to be allowed to fall, was surrounded by a helix and then its effect in falling sought for Now a body may either fall with a helix or through a helix *Covered copper wire, to the amount of 350* feet in length was made into a hollow cylindrical helix, about 4 inches long its internal diameter being 1 inch and its external diameter 2 inches It was attached to a line *running* upon an easy pulley, so that it could be raised 36 feet and then allowed to fall with an accelerated velocity on to a very soft cushion, its axis remaining vertical the whole time Long covered wires were made fast to its two extremities and these being twisted round each other, were attached to a very delicate galvanometer, placed about 50 feet aside from the line of fall, and on a level midway with its

[1] *Philosophical Transactions*, 1851, p 1 The Bakerian lecture.

course The accuracy of the connexion and the direction of the set of the needle were then both ascertained by the introduction of a feeble thermo-electric combination into the current

electric induction is produced Neither in rising nor in falling did this helix present any trace of action at the galvanometer, whether the con nection with the galvanometer was continued the whole time or whether it was cut off just before the diminution or cessation of motion

s the time before I was able to refer these currents to their true cause, but at last I traced them to the action of a part of the connecting wires proceeding from the helix to the galvanometer The two wires had been regularly twisted together, but the effect of many falls had opened a part near the middle distance into a sort of loop so that the wires instead of being tightly twisted together like the strands of a rope were separate for 3 feet as if the strands were open

equal and no effect at the galvanometer would have been produced as it was, currents in opposite directions but of unequal amounts of force tended to be produced and a current equal to the difference actually appeared Such a case is described in my earliest researches on terrestrial magno-electric induction (171) It is evident that the current should appear in the reverse direction, as the helix and wires are raised in the air and thus arose the reverse effect described above Therefore no positive or favourable evidence was supplied in favour of the original assumption by this use of a copper core in the helix

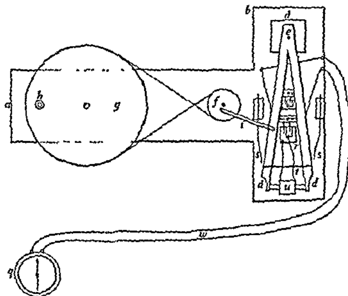
2707 The copper was selected as a heavy body and an excellent conductor of electricity On its dismissal a bismuth cylinder of equal size was employed to replace it as a substance

out effect

2710 In other experiments the helix was

these rods were made to rotate rapidly before and during their fall and many other condi

forces and of the effects that might be looked for consequent upon a condition of tension in



the motion, and that, whether the stopping was sudden or gradual, also that a motion downward quicker than that which gravity could communicate, would give more effect than the gravity result by itself, and that a corresponding increase in the velocity upwards would be proportionally effectual In such case a machine which could give a rapid alternating up and down motion, might be very useful in producing many minute units of inductive action in a small space and moderate time, for then, by proper commutators, the accelerated and retarded parts of each half-vibration could be separated and recombined into one consistent current, and this current could be sent through the galvanometer during the time its needle was swinging in one direction, and afterwards reversed for the time of a swing in the other direction, and so on alternately until the effect had become sensible, if any were produced by the assumed cause

2712 The machine which I had made for this purpose is that described in the last series of these *Researches* (2643), the electro magnet, the experimental core and the rod which carried them being removed *a*, *b*, *c* frame-board, *d*,*d*,*d* wooden lever, of which *e* is the axis, *f* the crank-wheel, and *g* the great wheel with its handle *h*, *i* the bar connecting the crank-wheel and lever, *q* the galvanometer, *r* the commutator, *w*, connecting wires, *s*, *s* springs of brass or copper, *t* a copper rod connecting the two arms of the lever to give strength, *u* the hollow helix fixed, or moveable at pleasure The plan is to a scale of one-fifteenth Being on a moveable frame, it could be placed in any position The cylinder of metal or other substance to be submitted to its action, was 5½ inches long and three-fourths of an inch in diameter, and was firmly held between the ends *d*, *d* of the lever arms The extent of the alternating motion was 3 inches A hollow cylindrical helix *u*, 2½ inches in length, and of such internal diameter that the cylinders could complete their rapid journeys to and fro within it without any danger of striking against its sides, was constructed, containing 516 feet of cov[illegible] thus cyl[illegible] or atta[illegible] ex-periment so as to move with it The wires from this helix passed to the commutators and from them to the galvanometer Part of the momentum of this machine was taken up by springs *s*, *s* (2648), and converted into the contrary motion, but so much remained undisposed of thus, that great care was required in fixing and strutting to render the action of the whole very steady, or else derangement quickly occurred at the cylinder and helix, and electro-currents were frequently produced.

2713 The employment of cylinders of iron, copper and other substances in this machine was competent to produce electro-currents in various ways Thus, iron might produce magneto-electric currents consequent upon its polar condition under the influence of the earth, these it would be easy to detect and separate by the use of adjusted magnets, which should neutralize or reverse the lines of magnetic force passing through the iron. Currents like those induced in copper cylinders and good conductors (2663, 2684), might be produced by the earth's action, but as the lines of gravitating force and of terrestrial magnetic force are inclined to each other, these might be separated by position, and it appeared that there was no source of error that might not by care be eliminated I will not occupy time by describing how this long lesson of care was learned, but pass at once to the chief results

2714 The copper cylinder (2712) was placed in the machine, and the helix fixed immoveably around it, the whole being in such a position that the cylinder should be vertical, and

move up and down parallel to the line of gravitating force within the helix However rapidly the machine was worked, or whatever the position of the commutator, there was no result at the galvanometer Cylinders of bismuth, glass, sulphur, gutta percha, *&c*, were also employed, but with the same negative conclusion

2715 Then the helix was taken from its fixed support and fastened on to the copper cylinder so as to move with it, and now very regular and comparatively large effects were produced After a while, however, these were traced to causes other than gravity, and of the following kind The helix was fixed at one end of a lever, at a point 22 inches from its axis, and being 2 inches in diameter its wires on one side were

were *across* the lines of magnetic force of the earth, electro-currents tended to form in these different parts proportionate in amount or strength to these numbers and the differences of these currents being continually gathered up by the *commutators were made sensible at the*

helix was just under the centre of motion, and the central line of the helix therefore, instead of being vertical, was horizontal Now the convolutions of the helix cut the lines of magnetic force in the most favourable manner, and the consequence was that the commutators were not required, for a single motion of the helix in one direction was sufficient to *show at the galvanometer* the magneto-electric currents induced If, on the contrary, the plane of motion was made horizontal, then no current was produced by any amount of motion for though the helix was as horizontal as, and not sensibly more so than before yet the parts of the convolutions which intersected the magnetic lines of force (being the upper and the lower parts) now moved with exactly equal velocity, and no differential result was produced

2716 The former small result (2715) was therefore probably dependent upon an effect of this kind and this was confirmed by placing the machine in such a position that the axis of the moving copper cylinder and helix should in its medium position be parallel to the line of the dip, and then no effect was produced Other bodies in the same position were equally unable to produce any effect

2717 Here end my trials for the present The *results are negative* They do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists

Royal Institution, July 19, 1850

TWENTY-FIFTH SERIES[1]

§ 31. *On the Magnetic and Diamagnetic Condition of Bodies* ¶ i *Non-expansion of Gaseous Bodies by Magnetic Force* ¶ ii *Differential Magnetic Action* ¶ iii *Magnetic Characters of Oxygen, Nitrogen and Space*

Received August 15, Read November 28, 1850

¶ i *Non-expansion of Gaseous Bodies by Magnetic Force*

2718 There can be no doubt that the magnetic force, the diamagnetic force, and the magneoptic or magnecrystallic force, will, when thoroughly understood, be found to unite or exist under one form of power, and be essentially the same Hence the great interest which exists in the development of any one of these modes of action, for differing so greatly as they do in very peculiar points, it is hardly possible that any one of them should be advanced in its illustration or comprehension, without a corresponding advance in the knowledge of the others Stimulated by such a feeling I have been engaged with Plucker, Weber, Reich and others in endeavouring to make out, with some

[1] *Philosophical Transactions* 1851 p 7

bismuth and diamagnetic bodies, the reverse of that in a magnet or in iron bodies, was one of the results of that conviction and desire

2719 Having failed however to establish the existence of such an antipolarity, and having shown, as I think, that the phenomena which were supposed to be due to it are in fact dependent upon other conditions and causes, I was induced, in the search after something precise as to the nature of diamagnetic bodies, to examine another idea which had arisen in consequence of the development of magnetic and diamagnetic phenomena amongst gaseous substances this thought, with some of the results which have grown out of it during its experimental examination, I purpose making the subject of the present paper

2720 Bancalari first showed that flame was diamagnetic[1] The effect, as I proved, was due chiefly to the heated state of gaseous portions of the flame,[2] but besides that, it appeared that at common temperatures diamagnetic phenomena could be exhibited by gases and also that in their production the gases differed very much one from another,[3] so that, taking common air, for instance, as a standard, nitrogen, and many other gases, were strongly diamagnetic in relation to it, whilst oxygen took on the appearance of a magnetic body, for *they* were repelled from, while it was attracted to, the place of maximum force in the magnetic field

2721 Recalling the general law given respecting the action of magnetic and diamagnetic bodies (2267, 2418), namely, that the former tended to go from weaker to stronger places, and the latter from stronger to weaker places of magnetic power, and applying it to such bodies as the gases, which are at the same time both highly elastic and easily changed in bulk by the superaddition of very small degrees of force, it would seem to follow, that if the particles of a diamagnetic gas tended to go from strong to weak places of action, in consequence of the direct and immediate effect of the magnetic power on them, then such a gas should tend to become enlarged or expanded in the magnetic field For, the amount of power by which the particles would tend to recede from the axis of the magnetic field, would be added to the expansive force by which they before resisted the pressure of the atmosphere, that pressure would therefore be in part sustained by the new force, and expansion would of necessity be the result On the other hand, if a gas were magnetic (as for instance oxygen), then the force cast upon the particles, by such a direct and immediate action of the magnetic power upon them, would urge them *towards* the axis of the magnetic field, and so coinciding with, and being superadded to the pressure of the atmosphere, would tend to cause contraction and diminution of bulk.

2722 If such supposititious cases were to prove true, we should then be able to arrive at the knowledge of the real zero-point (2416, 2432, 2440),[4] not amongst gases only, but amongst all bodies, and should be able to tell whether such a gas as oxygen were a magnetic or a diamagnetic body, and also able to range individual gases and other substances in their proper places And though I had originally endeavoured to ascertain whether there was any change in the bulk of air in the magnetic field, and found none, still Plücker's statement that he had obtained such an effect,[5] and the great enlargement of knowledge respecting the gases which since then we have acquired relating to their diamagnetic relations, and especially of the great difference which exists between them, encouraged me to proceed

2723 I first endeavoured to determine whether there was any affection of the layer of air (or other gas) immediately in contact with the magnetic pole, which, either by the consequent expansion or contraction of that layer, could render it able to affect the course of a ray of light and thus make manifest the changes occurring within A metal screen, with a pin hole in it, was set up before the flame of a bright lamp in a dark room, and thus an artificial star or small definite luminous object was formed Forty-six feet from it was placed the great horseshoe magnet (2247), ready to be excited by twenty pairs of Grove's plates, the poles were in a line, so that the ray from the lamp passed for 4 inches close to the surface of the first pole, then through 6 inches of air, and then, for 4 inches, close to the surface of the second pole A very fine refracting telescope, belonging to Sir James South, having an aperture of 3 inches and 46 inches focal length, received the ray The telescope was furnished with a perfect micrometer, so that the smallest change in the place of the luminous image could be observed on the threads The axis of the telescope was just above the level of the magnetic poles.

[1] *Philosophical Magazine*, 1847, Vol XXXI pp 401 421
[2] *Ibid.*, pp 404 406.
[3] *Ibid.*, p 409
[4] *Ibid* p 420
[5] *Annales de Chimie* 1850, Vol. XXIX, p. 134.

Not the smallest change in either the character or place of the luminous image could be observed either on the making or the breaking of the contact between the voltaic battery and the magnetic wire

2724 As the chief part of the light which came to the telescope consisted of rays which passed at some distance above the magnetic poles these were cut off by a screen which rising only one-eighth of an inch above the level of the poles allowed no ray to pass that was

est change in that or any other character occurred in the supervention or the withdrawal of the magnetic force

2725 The terminals of the magnetic poles were then varied so that the ray sometimes passed parallel and close to a long right-angled edge or parallel to and between two right-angled edges a little above or below them or over the line joining two hemispherical poles placed close together (and also in many other ways) but in no case did the magnetic action produce any effect upon the course of the ray

2726 In another form of the experiment the telescope was dismissed and a simple card with

2727

magnet Though the glass of the enclosing vessel disturbed the image of the object i e the point of light yet it was easy to perceive that no additional effect occurred when the magnetism was superinduced

such a degree as to cause any sensible change in its refractive force

2729 In order to compare the expected result with the real result due to change of volume I took a bar of iron 7 inches long and placed it so that the ray from the luminous object in passing to the eye should proceed by the side of the bar at not more than 1/60th of an inch from it and then raised the temperature of the bar gradually until by expanding the air in contact with it the course of the ray of light was sensibly affected to do this it required to be exalted many degrees When the air of the place was at 60° and the iron raised to 100° Fahr the effect was not distinct Hence it seemed that observation of the expected change of volume of the air would be rendered far more sensible by some arrangement measuring that change directly than by such means as those referred to above dependent on refractive force for it is certain that the change of volume in a very small quantity of air raised from 60° to 100° would be very evident by the former method On the other hand it was just

Hence the assumed necessity for examining those parts by a ray of light and every pre-

very slightly convex to include every variation of the experiment that might help to make any magnetic or diamagnetic effect whether special or local or general manifest but without effect

2730 I proceeded as these attempts had

Philosophical Magazine 1847 Vol XXXI 414 415

bismuth and diamagnetic bodies the reverse of that in a magnet or in iron bodies, was one of the results of that conviction and desire

2719 Having failed however to establish the existence of such an antipolarity, and having shown, as I think, that the phenomena which were supposed to be due to it are in fact dependent upon other conditions and causes, I was induced in the search after something precise as to the nature of diamagnetic bodies to examine another idea which had arisen in consequence of the development of magnetic and diamagnetic phenomena amongst gaseous substances this thought with some of the results which have grown out of it during its experimental examination I purpose making the subject of the present paper

2720 Bancalari first showed that flame was diamagnetic [1] The effect as I proved, was due chiefly to the heated state of gaseous portions of the flame [2] but besides that, it appeared that at common temperatures diamagnetic phenomena could be exhibited by gases and also that in their production the gases differed very much one from another [3] so that taking common air, for instance, as a standard nitrogen and many other gases, were strongly diamagnetic in relation to it, whilst oxygen took on the appearance of a magnetic body for they were repelled from while it was attracted to, the place of maximum force in the magnetic field

2721 Recalling the general law given respecting the action of magnetic and diamagnetic bodies (2267 2418) namely, that the former tended to go from weaker to stronger places, and the latter from stronger to weaker places of magnetic power, and applying it to such bodies as the gases, which are at the same time both highly elastic and easily changed in bulk by the superaddition of very small degrees of force, it would seem to follow that if the particles of a diamagnetic gas tended to go from strong to weak places of action in consequence of the direct and immediate effect of the magnetic power on them, then such a gas should tend to become enlarged or expanded in the magnetic field For, the amount of power by which the particles would tend to recede from the axis of the magnetic field, would be added to the expansive force by which they before resisted the pressure of the atmosphere, that pressure would therefore be in part sustained by the new force, and expansion would of necessity be the result On the other hand, if a gas were magnetic (as for instance oxygen), then the force cast upon the particles, by such a direct and immediate action of the magnetic power upon them, would urge them towards the axis of the magnetic field, and so coinciding with, and being superadded to the pressure of the atmosphere would tend to cause contraction and diminution of bulk.

2722 If such suppositious cases were to prove true we should then be able to arrive at the knowledge of the real zero-point (2416, 2432 2440) [4] not amongst gases only, but amongst all bodies and should be able to tell whether such a gas as oxygen were a magnetic or a diamagnetic body, and also able to range individual gases and other substances in their proper places And though I had originally endeavoured to ascertain whether there was any change in the bulk of air in the magnetic field, and found none still Plucker's statement that he had obtained such an effect,[5] and the great enlargement of knowledge respecting the gases which since then we have acquired relating to their diamagnetic relations, and especially of the great difference which exists between them, encouraged me to proceed

2723 I first endeavoured to determine whether there was any affection of the layer of air (or other gas) immediately in contact with the magnetic pole which, either by the consequent expansion or contraction of that layer, could render it able to affect the course of a ray of light and thus make manifest the changes occurring within A metal screen, with a pin-hole in it was set up before the flame of a bright lamp in a dark room and thus an artificial star or small definite luminous object was formed Forty-six feet from it was placed the great horse-shoe magnet (2247), ready to be excited by twenty pairs of Grove's plates, the poles were in a line so that the ray from the lamp passed for 4 inches close to the surface of the first pole, then through 6 inches of air, and then, for 4 inches, close to the surface of the second pole A very fine refracting telescope, belonging to Sir James South, having an aperture of 3 inches and 46 inches focal length, received the ray The telescope was furnished with a perfect micrometer, so that the smallest change in the place of the luminous image could be observed on the threads The axis of the telescope was just above the level of the magnetic poles.

[1] *Philosophical Magazine* 1847 Vol. XXXI pp. 401 421

[2] *Ibid.*, pp. 404, 406.

[3] *Ibid.*, p. 409

[4] *Ibid.* p. 470

[5] *Annales de Chimie* 1850, Vol. XXIX p. 134.

Not the smallest ch

the magnetic wire

2724 As the chief part of the light which came to the telescope consisted of rays which passed at some distance above the magnetic poles these were cut off by a screen which ris-

well marked by the micrometer Not the slight est change in that or any other character oc curred in the supervention or the withdrawal of the magnetic force

2725 The terminals of the magnetic poles were then varied so that the ray sometimes passed parallel and close to a long right-angled edge or parallel to and between two right-angled edges a little ab e or below them or

produce any effect upon the course of the ray

2726 In another form of the experiment the telescope was dismissed and a simple card with

point of light yet it was easy to perceive that no additional effect occurred when the mag netism was superinduced

pole of a very powerful magnet, it did not appear to be either expanded or condensed to such a degree as to cause any sensible change in its refractive force

2729 In order to compare the expected re-

ject in passing to the eye should proceed by the side of the bar at not more than 1/50th of an inch from it and then raised the temperature of the bar gradually until by expanding the air in contact with it the course of the ray of light was sensibly affected to do this it required to be exalted many degrees When the air of the place was at 60° and the iron raised to 100° Fahr the effect was not distinct Hence it seemed that observation of the expected change of volume of the air would be rendered far more sensible by some arrangement measuring that change directly than by such means as those referred to above dependent on refrac tive force for it is certain that the change of

very slightly convex to include every varia tion of the experiment that might help to make any magnetic or diamagnetic effect whether special or local or general manifest but with out effect

2730 I proceeded as these attempts had

[1] *Philosophical Magazine* 1847 Vol XXXI pp 414 415

square, having filed and flattened surfaces, were prepared, and also a sheet of copper, 1/10th of an inch in thickness and 3 inches square, having its middle part cut away to within 0 3 of an inch of the edge all round This plate or frame was then placed between the iron blocks, and the whole held together very tightly by copper screws, so as to make an air-chamber 1/10th of an inch wide and 2 4 inches square, having the faces of the blocks which were to become the magnetic poles, for its sides Three apertures and corresponding passages give access to the interior of this chamber, small stopcocks were attached to each By two of these, any gas, after it had been properly dried, could be sent into the chamber, or swept out of it, by any other entering gas and to the third was attached a gauge (2732) for the purpose of indicating and measuring any change of volume which might occur The edges of the central copper plate and the heads of the countersunk screws, were touched with white hard varnish, and the chamber thus rendered perfectly tight, *under every condition to which it had to be* subjected (*Fig 1*)

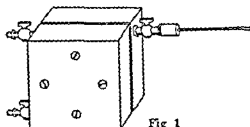


Fig 1

2732 The gauges were formed of small capillary tubes from 1 5 to 3 inches in length, the diameter in the middle of their length being less than one-half of that at either termination These were fixed at one end into a small socket, which screwed on to the third, or gauge-cock



Fig 2

mentioned above (2731) A minute portion of spirit, coloured by cochineal being put into the external end of this gauge, from a slip of wood or glass, immediately advanced to the middle or narrowest part, forming, as it always should do, a single portion of fluid By shutting the cock, this little cylinder could be easily retained in its place undisturbed during the filling of the air-chamber with gas, and the adjustment of its pressure to equality with that of the atmosphere On shutting the other cocks and opening the gauge-cock, the gauge was then ready to show any change of volume which the supervention of the magnetic force might cause, but to give it the highest degree of sensibility, it was necessary previously to make the liquid cylinder travel right and left of its place of rest, that the tube might be moistened on each side of the indicating fluid, an effect easily obtained by inclining the chamber to and fro, the gravity of the fluid making it pass one way or the other But this and many other necessary precautions as to position, temperature, &c, can only be learned from experience

2733 When this box was in its place, it stood between the poles of the great electro-magnet, with the plane of the gas-chamber in the equatorial position then square blocks of soft iron, resting on the magnet poles, were made to abut and bear against the sides of the box, so that in fact the inner faces of the air-chamber were the virtual magnetic poles, and being 3 inches square were only 1/10th of an inch apart Hence, *whatever air or gas was within the chamber,* would be subjected to a very powerful magnetic action, and could have very small changes in its bulk measured but it is perhaps necessary to observe that it would be contained in a field having everywhere lines of equal magnetic power (2463, 2465)

2734 *Air* was introduced into the box, and when all was properly arranged, the place of the indicating fluid was observed by a microscope Then the magnet was rendered powerfully active, and there appeared a very slight motion of the fluid, as if the air were a little expanded on taking off the magnetic force the fluid returned to its first place The same effect recurred again and again The amount of this change was very small, and there was reason to refer it to the pressure exercised by the magnet, when in action, upon the sides of the iron box, for afterwards, when the box was placed in a vice and squeezed, the same motion in the fluid occurred and further, when the square blocks of soft iron (2733) were kept apart by an under block of wood, so as not absolutely to touch and press the box, the effect was reduced to almost nothing

2735 Oxygen, nitrogen, carbonic acid and nitrous oxide gases, were then introduced successively into the iron box, and with exactly the same result as with air No difference appeared between oxygen and the other gases, greatly as they differ in magnetic and diamagnetic force and relations Hydrogen and coal-

gas were also subjected to experiment but when these gases were in the box there was a gradual recession of the indicating fluid, due, as I found, to the absorption of the gases, probably either by the varnish or cement or cork used at the gauge, or at the joints of the box The delicacy of the gauge was thus made manifest but when the effect was taken into ac

2736 The diameter of the gauge at the place where the fluid was placed was rather less than 1/100th of an inch An amount of motion equal to 1/100th of an inch was easily discerned

currence or the *absence* of change of volume in gases when under the magnetic influence appeared to me to be of great and almost equal importance, I was led to consider whether, in the experiment just described, the circumstance of the gases having been subjected to the magnetic power in a field of equal force (2733) might not have interfered with the production of the eff

entirely disappear I therefore constructed another apparatus so that this condition was removed and in which, if the particles of the diamagnetic gas by any unknown disposition of the



2738 A cylinder of soft

any diminution of its length from the pressure of the poles (2734), and that the diamagnetic phenomena would be abundantly produced in the parts from whence the iron had been removed The latter was found to be the fact for flame smoke, bismuth and other diamagnetic matter, when placed there passed equatorially very freely

2739 A copper tube 2 5 inches long made of metal 0 1 of an inch thick, was fitted to the

soft cement In this way it formed an annular air chamber round the iron, which when measured, was found to have a capacity of rather more than 2 cubic inches and included the most intense part of the magnetic field Three stopcocks were fitted into this copper jacket by two of which gas was passed into and out of

paratus with different gases and in order to obtain some idea of what might be expected by comparing one gas with another, I made a pre-

the light hydrogen in the heavy air is rendered very distinctly visible and it is seen on leaving the horizontal tube to turn at once upwards and to ascend rapidly, becoming wiredrawn in its course in consequence of its small

[1] *Philosophical Magazine* 1847 Vol XXXI p 41[?]
[2] *Philosophical Magazine*, 1847 Vol XXXI pp 413 414

rate of 6 cubic inches per minute, was placed exactly beneath the axial line, in the centre of the magnetic field When there was no magnetic force employed the hydrogen rose vertically, breaking against the points where the hemispherical poles touched but when the magnetic power was on, the stream of hydrogen divided into two parts, moving right and left, and ascended in two streams at a distance from the point of contact Now this division took place at a certain distance *below* the axial line and at that point notwithstanding the ascensive power of hydrogen in air or oxygen, it was constrained to go horizontally by the apparently repulsive power of the magnetic force, and did not in its further course approach nearer to the axial line, but formed a curve concentric with it, or nearly so, so that the compound streams of gas assumed exactly the shape of a tuning fork

2742 When air occupied the magnetic field, the division of the stream of hydrogen was 0 3 or 0 32 of an inch below the axial line When oxygen was about the poles, then the division of the hydrogen took place as far off as 0 55 of an inch below the axial line Hence at these distances the power which tended to make the hydrogen pass from the axial line, equatorially in the direction of the radius, was equal to the difference of the specific gravity of hydrogen compared with that of air and oxygen respectively At lesser distances the power would be much greater and indeed, if in any experiment the hydrogen was delivered nearer to the axial line, it was blown downwards and away with much force Calculating with these data, and still assuming that the diamagnetic gases receded from the axial line, in consequence of the direct action of the magnet and that only, causing them to pass from stronger to weaker places of action, I found, as I thought, reason to believe that the more diamagnetic gases, occupying the space within the copper box (2739), might probably be expanded at least 1/40 000th part of their volume by the magnetic force. Now the gauges that I employed were sensible when the fluid in them moved the 1/100th of an inch (2730), yet that space is only the 1/1 600 000th part of the capacity of the chamber, and therefore such an expansion as that above would have made it move through 0 4 of an inch, a quantity abundantly sufficient to render the result sensible if the fundamental assumption were correct

2743 *Air* was first submitted to the power of the great horseshoe magnet, urged by twenty pairs of Grove's plates in this apparatus (2739) The fluid moved very slightly outwards, as if a little expansion occurred on putting on the magnetic force, and returned when the force was taken off This small effect was found afterwards to be due to compression, occasioned by the tendency of the magnetic poles to approximate (2734)

2744 *Oxygen* presented exactly the same appearances as common air and to the same amount, so that no effect, due to magnetic or diamagnetic action, was here evident, but only that of the compression observed in the case of air (2743)

2745 *Nitrogen* gave exactly the same results as oxygen and air Now nitrogen is probably more diamagnetic than hydrogen, and should therefore have given a striking contrast with oxygen, if any positive results were to be obtained

2746 *Carbonic acid* and nitrous oxide gases yielded the same negative results, and, as I believe, when the apparatus was in an unexceptionable condition

2747 There is at the Pharmaceutical Society an excellent electro-magnet, of the horseshoe form similar in arrangement to our own (2247), but far more powerful, and thus through Mr Redwood I was favoured with the use of, for the repetition of the foregoing experiments at the house of the Society The iron, which is very soft and good in quality, is a square bar, 5 inches in thickness, and the medium line is 50 inches in *length* It has 1500 feet of copper wire, 0 175 *of* an inch in thickness, coiled round it and arranged (when I used it) in one continuous length The moveable terminal pieces for the poles are massive in proportion to the magnet Eighty pairs of Grove's plates were used to excite this magnet, and as it was found, by preliminary trials, that these were most powerful when arranged as four twenties, with their similar ends connected, they were so used, constituting a battery of twenty pairs of plates in which each platinum plate was 4x9 inches in the immersed part, and therefore presented 72 square inches of surface towards the active zinc

2748 On repeating the former experiments (2743) the effect of pressure was again evident, and it was manifest that the magnet itself, though 5 inches in thickness, was a little bent by the mutual attraction of its poles The effect was very small, because of the unity of the iron core passing through the centre of the experimental gas-chamber (2738) It was the on-

ly effect indicated by the gauge and was the

not the slightest trace of change of bulk in any of them appeared

2750 I think that the experiments are in every respect sufficient to decide that these

ly important in relation to the true nature of the magnetic force either as existing in, or acting upon the particles of bodies, and as in the magnetic field the force exhibits itself not as a central but as an axial power so the further distinction of the phenomena into such as are related to the axial direction (2733), and such as are related to or include the equatorial

Without the experiments the mind might have considered it very possible that one of these modes of expansion might have occurred and not the other

2751 No doubt it is true that even yet changes in volume in these directions may occur, provided the change in one direction is expansion and in the other contraction and that these are in amount equal to each other It was partly in reference to such possible changes (which may be considered as molecular), that the experiments with the ray of light were made (2723 2729), and also that in these and other experiments instituted for the purpose, a polarized ray was employed as the examiner but

the gases employed in the foregoing experiments possess or can assume are such as to make one ready to suppose, that if they show no tendency in any case to change in volume under the action of the magnet, so neither would any other gas or vapour do so but that all the individuals belonging to this great class

of bodies would be alike in that respect In connexion with this conclusion I may state that I have on former occasions and more lately, endeavoured to ascertain by the use of very delicate apparatus and powerful electro-magnets, whether any change was produced in the volume of such fluids as water, alcohol and solution of sulphate of iron but could observe no effect of the kind and I do not believe in its ex

part of the containing vessel which was not filled with metal, was occupied in one set of experiments by air and in another by alcohol, yet in no case could the least change in the volume of the iron or bismuth be observed however powerful the magnetic force to which they were submitted

tion of currents outwards or equatorially, i e in lines perpendicular to the magnetic axis, where pointed poles or the hour-glass core al

[1] *Philosophical Magazine* 1847 Vol XXXI 401 404 409

particles of dust or lycopodium, and the magnet in powerful action, no signs of currents in the air were visible Further, when a faint stream of diffuse cold smoke from a taper spark[1] was allowed to fall or rise a little on one side of the axial line, it was determined outwards and equatorially, but though it went outwards with the most force when equidistant from the two conical poles, or their representative parts in the double iron core (2738), still when it was made to pass near to one side, it continued to go outwards and equatorially, even when from its close vicinity to the iron surface, it had as it were to move over it, showing that the tendency of the smoke was outwards in *every part* of the magnetic field occupied by air or gas, and that therefore its motion was due to the action of the magnet on it as a diamagnetic, and not to currents of the air, which, if existing, would be inwards in one place or direction, and outwards in another

2755 When magnetic or diamagnetic fluids were subject to the magnetic force upon a plate of mica over the poles, according to the ingenious arrangement of Plucker they quickly assumed the different forms correspondent to their nature, but after that there was no further motion or current in them The cases are no doubt different to those where the whole of the magnetic field is occupied by the same medium, still, as far as it goes, it helps to confirm the conclusion that no currents are formed On putting the same liquids between the poles in glass cells, no magnetic currents could be observed in them, though fine particles were introduced into the fluids, for the purpose of making such changes of place visible, if they occurred

2756 So there is no evidence, either by the action on a ray of light (2727, 2729), or by any expansion or contraction (2750), or by the production of any currents (2754), that the magnet exerts any direct power of attraction or repulsion on the particles of the different gases tried, or that they move in the magnetic field, as they are known to do, by any such immediate attraction or repulsion

¶ ii *Differential Magnetic Action*

2757 Then what is the cause of the diamagnetic change of place? The effect is evidently a differential result, depending upon the *differences* of the two portions or masses of matter occupying the magnetic field, as the air and the streams of other gas in it,[2] or mercury and the tube of air in it (2407), or water and the piece of bismuth in it (2301), and though exhibited only in the action of masses, the latter must no doubt owe their differences to the qualities of the particles composing them Yet it is to be observed that no attempt to separate the perfectly mixed particles of very different substances has ever succeeded, though made with most powerful magnets Oxygen and nitrogen differ exceedingly, yet no appearance of the least degree of separation occurred in very powerful magnetic fields[3] In other experiments I have enclosed a dilute solution of sulphate of iron in a tube, and placed the lower end of the tube between the poles of a powerful horseshoe magnet for days together, in a place of perfectly uniform temperature, and yet without the least appearance of any concentration of the solution in that end which might indicate a tendency in the particles to separate

2758 The diamagnetic phenomena of the gases when considered as the differential result of the action of volumes of these bodies may be produced and examined in a very useful manner by the employment of soap-bubbles, as follows a glass tube was fitted with a cap, stopcock and bladder, so that any given gas contained in the bladder might be sent through it, and also with a foot or stand so that it might be placed in any required position The end of the tube was drawn down, bent at right angles, and cut off straight across at the extremity, being of the size and shape represented in *Fig 4*

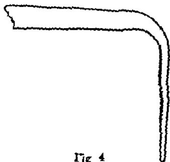


Fig 4

2759 It is easy to blow soap-bubbles at the end of such a tube, of any size up to an inch in diameter, and retain them for the time required by the action of the stopcock The soapy water

[1] *Philosophical Magazine* 1847 Vol XXXI p 403.

[2] *Philosophical Magazine* 1847, Vol. XXXI, p 409

[3] *Ibid*, p. 418.

should be prepared when wanted (and not be

en quite permanent enough for every useful

use

2760 If a bubble be blown with the end of the tube downwards and be half an inch in diameter, it will usually have a little extra water at the bottom, and will hang from the slender extremity of the tube by an attachment so small as to allow it great freedom of motion Hence it will swing to and fro like a pendulum, and according as there is more or less water at the bottom it will vibrate more or less rapidly, will as a whole gravitate more or less powerfully, and therefore will retain its perpendicularly dependent position with more or less stability —circumstances which are very useful in the employment of the bubble as a magnetic or

pipe is dipped in the soap-water, the end be touched with a piece of wood or glass rod which has also been kept in the soap water more or less of the liquid may be removed and by ob-

a certain amount of water and how little to give a bubble without any dependent water below and then it is just as easy, by arranging the amount of water beforehand to blow a bubble of any required character Even when no drop of water is left at the bottom still a range of thickness or thinness in the film itself can be obtained

2762 As the bubbles contain less and less of water, so are they rendered more sensitive in

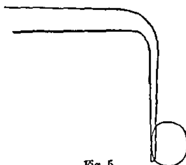


Fig 5

spaces or atmospheres an exceedingly delicate

the mouth of the tube be made broader the bubbles being thin can be retained standing on the extremity but as their attachment is

thickness for the same set of comparative experiments I usually employ them about half an inch in diameter

Fig 6

putting on the magnetic power by the use of twenty pair of plates the

tion was not great, and being due to the water of the bubble, gave an indication of the amount of that effect, to be used as a correction in experiments with other gases

2765 *Nitrogen in air* A bubble of nitrogen went outwards or equatorially in common air with a force much surpassing the outward tendency of a bubble of air (2764), in a very striking and illustrative manner It was often driven up from the end to the side of the tube and when on the side if presented inwards, it was driven to the outside of the tube, and however the tube was turned round, kept that position as long as the magnetic force was maintained This effect is the more striking when it is considered that four fifths of the air itself is nitrogen gas

2766 *Oxygen in air* The effect was very impressive, the bubble being pulled inwards or towards the axial line sharply and suddenly, exactly as if the oxygen were highly magnetic The result was expected, being in accordance with the phenomena presented by oxygen and nitrogen in a former investigation of the diamagnetic phenomena of the gases[1]

2767 *Nitrous oxide and olefiant gases in air* The bubbles went outwards or diamagnetically with a force much greater than that due to the effect of the water of the bubble, proving the relation of these gases to air, and according with the results formerly obtained with streams of these substances[2]

2768 There is no difficulty in applying this method of observation to experiments with gases in atmospheres of other gases than air, provided they be such as do not destroy the bubble but I do not consume time by detailing the results of such experiments, which accorded perfectly with those before obtained[3] The description given is quite sufficient to illustrate the point stated, namely, that the motion of the gases, one in another, when in the magnetic field, is a differential result, and supply sufficient cases for reference hereafter

2769 The same conclusion, that the effect is a differential result of the masses of matter present in the magnetic field, is also manifest from the consideration of the cases of gaseous, liquid, and solid diamagnetic bodies, advanced in a former part of these *Researches* (2405-14), and a conclusion of the same kind, as regards magnetic bodies, may also be drawn from experiments then described (2361 68)

¶ iii *Magnetic Characters of Oxygen, Nitrogen, and Space*

2770 The differential action of two portions of gas, or of any two bodies, may, by a more elaborate method, be examined in a manner far more interesting and important than that just described. The mode of action referred to may even be made the basis of instruments, by which, probably, most important indications and measurements of both magnetic and diamagnetic actions may be obtained, leading to results which are not even as yet contemplated by the imagination

2771 If two portions of matter, gaseous or liquid, are tied together and placed in a symmetric magnetic field, on opposite sides of the magnetic axis, they will be simultaneously affected If both are diamagnetic, or less magnetic than the medium occupying the magnetic field, both will tend to go outwards or equatorially, equally if they are alike, but unequally if they differ The consequence will be that, if they are placed, in the first instance, equidistant from the magnetic axis, the supervention of the magnetic force will not alter their position provided they be alike, but if they differ, then their position will be changed, for the most diamagnetic will move outwards equatorially, pulling the least diamagnetic inwards until the two are in such new positions that the forces acting on them are equipoised, and they will assume a position of stable equilibrium Now the distance through which they will move may be used indirectly, or better still, the force required to restore them to their equidistant position may be employed directly to estimate the tendency each had to go from the magnetic axis, that is, to give their relative diamagnetic intensities

2772 That I might submit gases to such a method of examination, I selected a piece of very thin and regular flint-glass tube, about ⅗ths of an inch external diameter, and not more than ¹⁄₆₀th of an inch in thickness, and drawing at the blow-pipe lamp two equable portions of this tube into the shape and size represented, *Fig* 7, in which the barrel part is 1½ inches long, I filled one with oxygen gas and the other with nitrogen gas, and then sealed them up hermetically The end of the prolonged part of each was touched whilst warm with sealing wax and a thread fastened to it, which thread was tied into a loop, also represented of full size By these the tubes were to be suspended perpendicularly from a torsion balance, so that the middle of each should, when in place, be on a level with the magnetic axis

[1] *Philosophical Magazine* 1847, Vol XXXI, pp 410 415
[2] *Ibid*, p 411.
[3] *Ibid*., pp 414, 415.

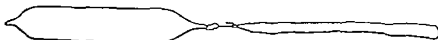


Fig 7

2773 The torsion balance consisted of a bundle of sixty equally stretched cocoon silk fibres,

circumstances, if any motion was given to the balance, so as to make its arm vibrate, the vibrations

swung beyond its new place of rest and then returned with considerable power, vibrating many times in the period, which before was filled by a single oscillation, and when it had come to its place of rest, or of stable equilibrium, the oxygen tube was about one-eighth of an inch from the iron of the core, and the nitrogen

self-adjustment of the oxygen and nitrogen, as regards their place in relation to the magnetic axis, are very simple and evident In the first place, the *glass* of the tubes is more diamagnetic than the surrounding medium or air (2424), and therefore each tends to move outwards; but being equal in nature and condition to each other, they tend to move with equal force when at equal distances, and at those distances compensate each other If one be driven inwards, it is subjected to a greater exertion of force by coming into a more intense part of the magnetic field, and the other, being

2776 The *contents* also of the tubes are sub-

wards more powerfully than the oxygen, and the difference must exist to a very great degree, for it is such as to carry the glass of the oxygen tube up to a position so near the axis that it could not by itself, or with mere air inside, retain it for a moment without the aid of considerable restraint The power with which the tubes only would retain their equidistant position, combined with the extent to which they are displaced from this position, shows

lation to the air and their mechanical connex-

[1] *Philosophical Magazine*, 1847, Vol 409

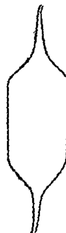
equidistant, is the measure of their magnetic or diamagnetic differences

2777 Having thus explained the general principles of action, I will not at present go into their application in the construction of a measuring instrument or the results obtained with it, further than is required for the general elucidation of magnetic and diamagnetic bodies, and the determination of the true zero-point (2721, 2722)

2778 The principles just described enabled me to return to a method of investigation which on a former occasion greatly excited my hopes (2433), but which seemed then suddenly cut off by want of power Various bodies, whether considered as magnetic or diamagnetic substances, admit of two modes of treatment, which promise to be exceedingly instructive as regards their properties and their destined purposes in natural operation A gas may be *heated* or *cooled*, and the effect of temperature, which is known to be very influential,[1] may now be ascertained without any change in the bulk of the gas, or it may be *rarefied* and *condensed* through a very extensive range, and the effect of this kind of change upon it ascertained independent of temperature or the presence of any other substance Solids and liquids do not admit of these methods of examination, and do not therefore assist in the determination of the zero-point and of the true distinction of magnetic and diamagnetic bodies in the same manner that the gases do

2779 It appeared to me that if a gaseous body were magnetic, then its magnetic properties ought to be diminished *in proportion* as it was rarefied, i e, that equal volumes of such a gas at different pressures ought to be more magnetic, as they are denser, on the other hand, that if a gas were diamagnetic, rarefaction ought to diminish its diamagnetic character, until, when reduced to the condition of a vacuum, it should disappear In other words, if two opposed portions of the same magnetic gas, one rarer than the other, were subjected at once to the magnetic force, the *denser* ought to approach the axial line, or be drawn into the place of most intense action, whereas if two similarly opposed portions of a diamagnetic gas were subjected to the magnetic action, the more expanded or *rarer* gas ought to go inwards to the place of strongest action

2780 Several bulbs of oxygen (*Fig 8*), similar in arrangement to those already described (2772), and very nearly alike in size, were prepared and hermetically sealed, after that the quantity of gas within them had been reduced to a certain degree by the air pump The first contained the gas at the pressure of one atmosphere, the second had the gas at half an atmosphere, or 15 inches of mercury, the third contained gas at the pressure of 10 inches of mercury, and the fourth, after being filled with oxygen, was reduced to as good a vacuum as an excellent air pump could effect When the first of these was compared with the other three, the effect was most striking, opposed to the half atmosphere, it went towards the axis, driving the expanded portion away, when in relation to the one-third atmosphere, it went inwards or axially with still more power, and when opposed to the oxygen vacuum, it took its place as close to the iron core as in the former case, when contrasted with nitrogen (2774), and it was manifest that the diamagnetic power of the glass tube which inclosed it (2775), was the only thing which prevented the oxygen from pressing against the iron core occupying the centre of the magnetic field


Fig 8

2781 On experimenting with the other tubes exactly the same result was obtained Thus the tube with one-third of an atmosphere, in association with the vacuum tube, went inwards, driving the other outwards, i e, it was more magnetic than the vacuum, but in association with the one-half atmosphere tube it went outwards, whilst the denser gas passed inwards Any one of the tubes, if associated with another having a rarer atmosphere, passed inwards or magnetically, whilst if associated with others having denser atmospheres it passed outwards, being driven off by the superior magnetic force of the denser gas As far as I could ascertain in these preliminary forms of experiment, the tendency inwards or axially appeared to be in proportion to the density of the gas but the exact measurement of these forces will be given hereafter.

2782 Thus oxygen appears to be a very magnetic substance, for it passes axially, or from weaker to stronger places of force, with considerable power a conclusion in accordance with the result of former observations[2] Moreover

[1] *Philosophical Magazine*, 1847, Vol. XXXI, pp. 406, 417

[2] *Philosophical Magazine* 1847, Vol. XXXI pp 410, 415

it passes more powerfully when dense than

force remains No doubt it may be said that

oxygen is therefore a truly magnetic body

2783 *Nitrogen* being the other and larger part of the atmosphere, was then subjected to experiment and three tubes, one containing the gas at a pressure of 30 inches of mercury, another with the gas at the pressure of 15 inches and the third reduced as nearly as it could be to a vacuum, were prepared (2780) When these were compared one with another in the magnetic field, they were found to be so nearly alike as not to be distinguishable from each other i e, they remained equidistant from the magnetic axis I do not mean to imply that nitrogen at these different pressures is absolutely the same bulk for bulk (an instrument now under construction will enable me hereafter to compare and measure with infinitely

2784 Nitrogen therefore appears to be neither magnetic nor diamagnetic if it were either, it could not but fall in its specific condition as it was rarefied, as it is it is equivalent to a vacuum If a given space be considered as a vacuum into which oxygen or nitrogen is to be

neither magnetic nor diamagnetic, but like space itself

produced by rarefaction For the present I may mention olefiant gas and cyanogen as substances which appear to proceed inwards, or towards the axial line as they are more rarefied They are therefore not merely at zero, but

make it diamagnetic as oxygen renders it magnetic then flint glass or phosphorus presents us with such a substance When these bodies are made into forms similar to the volumes of nitrogen or the vacua in size and shape and are compared with them on the torsion balance they pass outwards with much force and it is probably the great diamagnetic force of the glass of the tubes that prevents the effect of rarefaction from being more evident in olefiant and other gases

2786 When a tube has been filled with a particular gas, then exhausted as much as possible and sealed up hermetically it may be considered as inclosing what is commonly call-

they will ultimately be nearly [illegible]

tion of *space* free from any material substance

manifest that the lines of magnetic force (2149) can traverse pure space, just as gravitating force does, and as static electrical forces do (1616), and therefore space has a magnetic relation of its own, and one that we shall probably find hereafter to be of the utmost importance in natural phenomena But this character of space is not of the same kind as that which, in relation to matter, we endeavour to express by the terms magnetic and diamagnetic To confuse them together would be to confound space with matter and to trouble all the conceptions by which we endeavour to understand and work out a progressively clearer view of the mode of action and the laws of natural forces It would be as if in gravitation or electric forces (1613), one were to confound the particles acting on each other with the space across which they are acting, and would, I think shut the door to advancement Mere space cannot act as matter acts, even though the utmost latitude be allowed to the hypothesis of an ether, and admitting that hypothesis, it would be a large additional assumption to suppose that the lines of magnetic force are vibrations carried on by it (2591), whilst as yet, we have no proof or indication that time is required for their propagation or in what respect they may in general character assimilate to, or differ from, the respective lines of gravitating luminiferous, or electric forces

2788 Neither can space be supposed to have those circular currents round points diffused through it, which Ampère s theory assumes to exist around the particles of ordinary magnetic matter, and which I had for a moment supposed might exist in the contrary direction round the particles of diamagnetic matter (2429, 2640, &c) The imagination, restrained by philosophical considerations, fails to find anything in pure space about which the currents could circulate, or to which they could by any association be attached, and the difficulty, if already not immeasurable, would be still greater to those, if there be any, who, assuming that magnetic and diamagnetic bodies are alike in nature, must assume that there are like currents in both for it does not seem possible to add (for instance) phosphorus having such a magnetic constitution, to space supposed to be of a similar constitution, and yet to have as a result a diminution of the magnetic powers of the space so occupied

2789 As space therefore comports itself independently of matter, and after another manner, the different varieties of matter must, in relation to their respective qualities, be considered amongst themselves Those which produce no effect when added to space, appear to me to be neutral or to stand at zero Those which bring with them an effect of one kind will be on the one side of zero, and those which produce an effect of the contrary kind will be on the other side of zero, by this division they constitute the two subdivisions of magnetic and diamagnetic bodies The law which I formerly ventured to give (2267, 2418), still expresses accurately their relations for in an absolute vacuum or free space, a magnetic body tends from weaker to stronger places of magnetic action, and a diamagnetic body under similar conditions from stronger to weaker places of action

2790 Now that the *true zero* is obtained, and the great variety of material substances satisfactorily divided into two general classes, it appears to me that we want another name for the magnetic class, that we may avoid confusion The word *magnetic* ought to be general, and include *all* the phenomena and effects produced by the power But then a word for the subdivision, opposed to the diamagnetic class is necessary As the language of this branch of science may soon require general and careful changes, I assisted by a kind friend, have thought that a word not selected with particular care might be provisionally useful, and as the magnetism of iron, nickel and cobalt, when in the magnetic field, is like that of the earth as a whole, so that when rendered active they place themselves parallel to its axes or lines of magnetic force, I have supposed that they and their similars (including oxygen now) might be called paramagnetic bodies, giving the following division

Magnetic { Paramagnetic / Diamagnetic

If the attempt to facilitate expression be not accepted I hope it will be excused

2791 From the presence of oxygen in the air, the latter is, as a whole, a magnetic medium of no small power Hence all the comparative experiments on the diamagnetic condition of other gases, made by passing streams of them through it and through each other,[1] require a correction which occasionally may place some of these bodies on the paramagnetic side of zero Even solid and fluid substances may be

[1] *Philosophical Magazine* 1847, Vol. XXXI pp 407 420 &c

thus affected and the preliminary list which I formerly gave (2424) will need alteration in this respect I hope soon however to have the means of ascertaining not only the place of bodies but also their relative degrees of force at the same and at different temperatures with a degree of accuracy that will serve great purposes in the further development of this branch of science

2792 Am n t the g h hort exam ed

sulphurous acid hydr odic acid ammonia sul phuretted hydrogen coal gas ether vapour and sulphuret of carbon vapour for though

taining one atmosphere is not quite 0 34 of a cub c inch and the we ght therefore of the oxy gen within 0 117 of a grain I endeavoured to compare th s quantity n the first place with soft iron and therefore attached a portion of that metal having one-tenth of this weight or

exhausted and hermetically sealed Be ng now opposed to the oxygen tube in the magnetic

vas employed for the compar son

2794 One hundred grains of clean good crystallized protosulphate of iron were d ssolved in distilled water and diluted until a glass bulb of nearly the same size as the oxygen

p esent modes of observat o
solut on had this strength it occup ed the bulk

combination

2795 Again the oxygen tubes contain ng respect vely one atmosphere and a vacuum (2780) were adjusted about an inch apart and

tube Being taken away it was set up in the horizontal pos tion (after being turned 90° on its axis so that the flexure might be in the

net c power

2796 It is hardly necessary for me to say here that this oxygen cannot exist in the atmospl ere exert ng such a remarkable and high amount of magnet c force without having a most important influence on the disposition of

the magnetism of the earth as a planet, especially if it be remembered that its magnetic condition is greatly altered by variations in its density (2781) and by variations in its temperature[1] I think I see here the real cause of many of the variations of that force, which have been, and are now, so carefully watched on different parts of the surface of the globe The daily variation and the annual variation both seem likely to come under it also very many of the irregular continual variations which the photographic process of record renders so beautifully manifest If such expectations be confirmed, and the influence of the atmosphere be found able to produce results like these, then we shall probably find a new relation between the aurora borealis and the magnetism of the earth, namely, a relation established, more or less, through the air itself in connection with the space above it, and even magnetic relations and variations which are not as yet suspected, may be suggested and rendered manifest and measurable, in the further development of what I will vent[illegible] *magne*[illegible].

[illegible] simplicity and s[illegible] cause assumed, as it at present appears to my mind As soon as I have sufficiently submitted these views to a close consideration and the test of accordance with observation, and where applicable with experiments also, I will do myself the honour to bring them before the Royal Society.

Royal Institution, August 2, 1850

[1] *Philosophical Magazine* 1847 Vol XXXI p 417

TWENTY-SIXTH SERIES[1]

§ 32 *Magnetic Conducting Power* ¶ i *Magnetic Conduction* ¶ ii. *Conduction Polarity* ¶ iii *Magnecrystallic Conduction* § 33 *Atmospheric Magnetism* ¶ i *General Principles*

RECEIVED OCTOBER 9,[2] READ NOVEMBER 28, 1850

¶ i *Magnetic Conduction*

2797 THE remarkable results given in a former series of these *Researches* (2757, &c) respecting the powerful tendency of certain gaseous substances to proceed either to or from the central line of magnetic force, according to their relation to other substances present at the same time, and yet the absence of all condensation or expansion of these bodies (2756) which might be supposed to be consequent on such an amount of attractive or repulsive force as would be thought needful to produce this tendency and determination to particular places, have, upon consideration, led me to the idea, that if bodies possess different degrees of *conducting power* for magnetism, that difference may account for all the phenomena, and, further, that if such an idea be considered, it may assist in developing the nature of magnetic force I shall therefore venture to think and speak freely on this matter for a while, for the purpose of drawing others into a consideration of the subject, though I run the risk, in doing so, of falling into error through imperfect experiments and reasoning As yet, however, I only state the case hypothetically, and use the phrase *conducting power* as a general expression of the capability which bodies may possess of affecting the transmission of magnetic force, implying nothing as to how the process of conduction is carried on Thus limited in sense, the phrase may be very useful, enabling us to take, for a time, a connected, consistent and general view of a large class of phenomena, may serve as a standard of meaning amongst them, and yet need not necessarily involve any error, inasmuch as whatever may be the principles and condition of conduction, the phenomena dependent on it must consist among themselves

2798 If a medium having a certain conducting power occupy the magnetic field, and then a portion of another medium or substance be placed in the field having a greater conducting power, the latter will tend to draw up towards the place of greatest force, displacing the former Such at least is the case with bodies that are freely magnetic, as iron, nickel, cobalt and their combinations (2357, 2363, 2367, &c), and

[1] *Philosophical Transactions* 1851, p 29

[2] Revised by the author and returned by him November 12 1850.

such a result is in analogy with the phenomena

um of stronger power by this differential kind

a single gas occupying the magnetic field (2754), for any one particle can then conduct as well as any other, and therefore will keep its place; and it also agrees, I think, with the unchangeability of volume (2750).

2800 In reference to the latter point, we have to consider that the force which urges such a body as oxygen towards the middle of the field is not a central force like gravitation, or the mutual attraction of a set of particles for each other, but an axial force, which, being very different in character in the direction of the axis and of the radii, may, and must produce its effect in a very different manner to a purely central force That these differences exist, is manifest by the action of transparent bodies, when in the magnetic field, upon a ray of light, and also by the ordinary action of magnetic bodies and hence, perhaps, the reason

seem equal to that effect (2766).

2801. So when two separate portions of oxygen or nitrogen are in the magnetic field, the one passes inwards and the other outwards, without any contraction or expansion of their relative volumes, and the result is differential,

immersed

ies which, like oxygen, facilitate the transmission of this power more or less, they class together as magnetic or paramagnetic substances (2790), and those bodies, which, like olefiant gas or phosphorus, give more or less obstruction, may be arranged together as the diamagnetic class Perhaps it is not correct to express both these qualities by the term *conduction*, but in the present state of the subject, and under the reservation already made (2797), the phrase may I think be employed conveniently

diamagnetic substances, then the internal processes by which they perform their functions can hardly be the same, though they might be similar Thus they *may* have circular electric currents in opposite directions, but their *distinction can scarcely be supposed to depend* upon the difference of force of currents in the *same* direction. If the view be correct also, though the results obtained when two bodies are simultaneously present in the magnetic field may be considered as differential (2768,

stanced, it tends to go from stronger to weaker places of action, or is *repelled* (2756)

2804 Matter, when its powers are under

netic bodies, may well be expected This evidence exists, but as certain considerations connected with polarity preclude me from calling too freely upon iron, cobalt, or nickel (2832) *for illustrations, and as in other bodies which* are paramagnetic, as well as in those that are diamagnetic, the effects are very weak, they will be better comprehended after some further general consideration of the subject (2843)

2806 I will now endeavour to consider what *the influence is which paramagnetic and diamagnetic bodies* viewed as conductors (2797), exert upon the lines of force in a magnetic field Any portion of space traversed by lines of magnetic power, may be taken as such a field, and there is probably no space without them The condition of the field may vary in intensity of *power, from place to place, either along the* lines or across them, but it will be better to assume for the present consideration a field of equal force throughout, and I have formerly described how this may, for a certain limited space, be produced (2465) In such a field the power does not vary either along or across the *lines, but the distinction of direction is as great* and important as ever, and has been already marked and expressed by the term axial and equatorial, according as it is either parallel or transverse to the magnetic axis

2807 When a paramagnetic conductor, as for instance, a sphere of oxygen, is introduced into such a magnetic field, *considered previously* as free from matter it will cause a concentration of the lines of force on and through it, so that the space occupied by it transmits more magnetic power than before (*Fig 1*) If, on the other hand, a sphere of diamagnetic matter be placed in a simi*lar field, it will cause a di*vergence or opening out of the lines in the equatorial direction (*Fig 2*), and less magnetic power will be transmitted through the space it occupies than if it were away

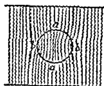


Fig 1

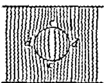


Fig 2

2808. In this manner these two bodies will be found to affect *first* the *direction* of the lines of force, not only within the space occupied by themselves, but also in the neighbouring space, into which the lines passing through them are prolonged, and this change in the course of the lines will be in the contrary direction for the two cases

2809 *Secondly*, they will affect the *amount* of force in any particular part of the space within *or near them, for as every section across the* line of such a magnetic field must be definite in amount of force, and be in that respect the same as every other section, so it is impossible to cause a concentration within the sphere of oxygen (*Fig 1*) without causing also a simultaneous concentration in the parts axially sit*uated as a a outside of it, and a corresponding* diminution in the parts equatorially placed, *b b* On the other hand, the diamagnetic body (*Fig 2*) will cause diminution of the magnetic force in the parts of space axially placed in respect of it, *c c*, and concentration in the near equatorial parts, *d d* If the magnetic field be *considered as limited in its extent by the walls* of iron forming the faces of opposed poles (2465), then even the distribution of the magnetism within the iron itself will be affected by the presence of the paramagnetic or diamagnetic bodies, and this will happen to a very large extent indeed, when, from among the *paramagnetic class, such substances as iron*, nickel or cobalt are selected

2810 The influence of this disturbance of the forces upon the place and position of either a paramagnetic or a diamagnetic body placed within the magnetic field, is readily deduced upon consideration and easily made manifest *by experiment A small sphere of iron* placed within a field of equal magnetic power, bounded by the iron poles has a position of unstable equilibrium, equidistant from the iron surfaces, and at such time a great concentration of force takes place through it, and at the iron faces opposite to it, and through the intervening axial spaces If the sphere be on either side of the middle distance, it flies to the nearest iron surface, and then can determine the greatest *amount of magnetic force to or upon the axial lines which pass through it*

2811 If the iron be a spheroid, then its greatest diameter points axially, whether it be in the position of unstable equilibrium, nearer to or in contact with the iron walls of the field *As* the circumstances are now more favourable for the concentration of force in the axial line *passing through the body than before*, so this result can be produced by much weaker paramagnetics than iron, and I have no doubt could easily be produced by a vessel of oxygen or nitric oxide gas (2782, 2792) It now becomes indeed a form, though not the best, of that ex

periment by which the magnetic condition of bodies is considered as most sensitively tested

2812 The relative deficiency of power in diamagnetic bodies renders any attempt to obtain the converse phenomena to those of iron somewhat difficult in order therefore to exalt the conditions I used a saturated solution of protosulphate of iron in the magnetic field by this means I strengthened the lines of power passing across it without disturbing its equality in the parts employed, or introducing any error into the principle of the experiment and

spot where the paramagnetic body had unstable equilibrium When the cylinder was suspended horizontally then the direction it took was equatorial and this effect also was very clear and distinct

2813 These relative and reverse positions of paramagnetic and diamagnetic bodies in a field of equal magnetic force accord well with their known relations to each other and with the kind of action already laid down in principle (2807) as that which they exert on the magnetic power to which they are subjected One may retain them in the mind by conceiving that if a liquid sphere of a paramagnetic conductor were in the place of action and then the magnetic force developed it would change

come an oblate spheroid

2815 With diamagnetic bodies the mutual action is more difficult to determine because of the comparative lowness of their condition I therefore resorted to the expedient before described of using a saturated solution of protosulphate of iron as the medium occupying the field of equal magnetic force, and employ-

when the phosphorus cylinder was in the middle of the magnetic field it was free to move equatorially or across the lines of magnetic force it however had *no tendency* to do so under

across the lines of magnet

exist

other

tion of protosulphate of iron, so paramagnetic and diamagnetic bodies attract each other equatorially in a mean medium, but each repels bodies of its own kind (2831)

¶ ii *Conduction Polarity*

2818 Having thus considered briefly the effects which the disturbance of the lines of force, by the presence of paramagnetic and diamagnetic bodies is competent to produce (2807, &c), I will ask attention to that which may be considered as their polarity not wishing by the term to indicate any internal condition of the substances or their particles, but the condition of the mass as a whole, in respect to the state into which it is brought by its own disturbance of the lines of magnetic force and that, both in regard to its condition with respect to other bodies similarly affected and also in regard to differences existing in different parts of its own mass Such a condition concerns what may be called *conduction polarity* Bodies in free space, when under magnetic action will possess it in its simplest condition but bodies immersed in other media will also possess it under more complicated forms, and its amount may then be varied, being reversed or increased, or diminished to a very large extent

2819 Taking the simplest case of paramagnetic polarity, or that presented in Fig 1 (2807), it consists in a convergence of the lines of magnetic force on to two opposed parts of the body, which are to each other in the direction of the magnetic axis The difference in character of the two poles at these parts is very great, being that which is due to the known difference of quality in the two opposite directions of the line of magnetic force Whether polar attraction or repulsion exists amongst paramagnetic bodies, when they present mere cases of conduction (as oxygen, for instance), is not yet certain (2827), but it probably does, and if so, will doubtless be consistent with the attraction and repulsion of *magnets* having correspondent poles.

2820 When we consider the conduction polarity of a diamagnetic body, matters appear altogether different It has not a polarity like that of a paramagnetic substance, or one the mere reverse (in name or direction of the lines of force) of such a substance, as I, Weber and others have at times assumed (2640), but a state of its own altogether special Its polarity consists of a divergence of the lines of power on to, or a convergence from the parts, which being opposite, are in the direction of the magnetic axis, so that these poles, having the same general and opposite relations to each other, which correspond to the differences in the poles of paramagnetic bodies, have still, under the circumstances, that striking contrast and difference from the polarity of the latter bodies which is given by convergence and divergence of the lines of force.

2821 Let *Fig 3* represent a limited magnetic field with a paramagnetic body P, and a diamagnetic body D, in it, and let N and S represent the two walls of iron associated with the magnet (2465) which form its boundary, we shall then be able to obtain a clear idea of the direction of the lines of magnetic force in the field Now the two bodies, P and D, cannot be represented by supposing merely that they have the same polarities in opposite directions. The 1 polarity of P is importantly unlike the 3 polarity of D but if D be considered as having the reverse polarities of P, then the one polarity of P should be like the 4 polarity of D, whereas it is more unlike to that than to the 3 polarity of D, or even to its own 2 polarity

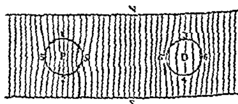


Fig 3

2822 There are therefore two essential differences in the nature of the polarities dependent on conduction the difference in the direction of the lines of force abutting on the polar surfaces, when the comparison is with a magnet reversed, and the difference of convergence and divergence of these lines, when compared with a magnet not reversed, and hence a diamagnetic body is not in that condition of polarity which may be represented by turning a paramagnetic body end for end, while it retains its magnetic state

2823 Diamagnetic bodies in media more diamagnetic than themselves would have the polar condition of paramagnetic bodies (2819), and in like manner paramagnetic conductors in media more paramagnetic than themselves would have the polarity of diamagnetic bodies

2824 Besides these differences the bodies must have an equatorial condition, which, in the two classes of conductors, would be able to produce corresponding effects. The whole of

these . . . ..

like correspondence in the equatorial parts of D either to itself or to space, but these parts in P or in D d . . .

. . . exist as a consequence of the definite character of any given section of the magnetic field (2809)

2825 Though the experimental results of these polarities are not absent, still they are not very evident or capable of being embodied in many striking forms, and that because of the extreme weakness of the forces brought into play, as compared with those larger forces exhibited in the mutual action of magnets Hence it is, that the many attempts to show a polarity in bismuth have either failed, or other phenomena have been mistaken for those properly referable to such a cause The highest, and therefore the most delicate, test of polarity we possess, is in the subjection of the polar body to the line of direction of magnetic forces of a very high degree, when developed around it and hence . . .

paramagnetic or diamagnetic conductors in many cases, when the action of these same poles is abundantly manifest in their relation to the almost infinitely stronger poles of a powerful horseshoe or electro-magnet

2826 I took a tube *a* (*Fig* 4), filled with a saturated solution of sulphate of cobalt, and suspended it between the poles of the great electro-magnet, it set readily and well Another tube, *b*, was then filled with a saturated solution of sulphate of iron, and being associated with the S pole of the magnet, was brought near the cobalt tube in the manner shown, but not the slightest effect on the position of *a* was observable The tube *b* was changed into the position *c*, to double any effect that might be present, but no trace of mutual action between the poles of *a* and *b* was visible (2819)



Fig 4

2827 To increase the effect, the magnetic solution tube was suspended in water, as a good diamagnetic medium, between flat-faced poles (*Fig* 5) It pointed well Two bottles of saturated solution of sulphate of iron were

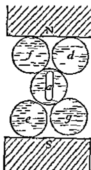


Fig 5

made the same kind of experiment with an air-tube in water in which case it points axially (2406), with the same negative result I do not mean to assert that there was absolutely no effect produced in these cases (2819) but if any, it must have been inappreciably small, and shows how unfit such means are to compare with those which are supplied by the pointing of a body when under the influence of powerful magnets If polarity cannot be found by these methods in paramagnetic bodies so strongly influential as saturated solution of iron, nickel or cobalt, it can hardly be expected to manifest itself by analogous actions in the much weaker cases of diamagnetic substances

2828 When a spherical paramagnetic conductor is placed midway in a field of equal magnetic force, it occupies a place of unstable equilibrium, from which, if it be displaced ever so little, it will continue to move until it has gained the iron boundary walls of the field (2465, 2810), this is a consequence of its particular polar condition If the sphere were free

2829 So also in the case of diamagnetic bodies their peculiar condition of polarity is shown

the equatorial pointing of an elongated portion (2812) If pointed magnetic poles are used then the effects are very much stronger, but are exactly the same in kind, and dependent upon the same causes and polar conditions

2830 There are another set of effects produced which are either the results of the axial polarity just referred to, or else may be considered as consequences of the condition of the

equatorial parts of the conductors (2824) Two balls of iron, in a field of equal force, if retained in a plane at right angles to the line of force, i e, with their equatorial parts in juxtaposition, separate from each other with considerable power (2814), and the probability is that two infinitely weaker bodies of the paramagnetic class would separate in like manner Two portions of phosphorus, being a diamagnetic substance, have been found also to separate under the same circumstances (2815)

2831 The motions here are of the same kind, whereas they might have been expected to be the *reverse* (2816), of each other still they are perfectly consistent The diamagnetics ought to separate for the field is stronger in lines of magnetic force between them than on the outsides as may easily be seen by considering the two spheres D D in *Fig 6* and therefore this motion is consistent and is in accordance generally with the opening or set equatorially, either of separate portions or of a continuous mass of such substances (2829), in their tendency to go from stronger to weaker places of action On the other hand, the two balls of iron, P P have weaker lines of force between them than on the outside and as their tendency is to pass from weaker to stronger places of action, they also separate to fulfil the requisite condition of equilibrium of forces Finally, a paramagnetic and a diamagnetic body attract each other (2817) and they ought to do so, for the diamagnetic body finds a place of weaker action towards the paramagnetic body, and the paramagnetic substance finds a place of stronger action in the vicinity of the diamagnetic body D P, *Fig 6*

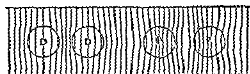


Fig 6

2832 *I have frequently* spoken of iron in illustration of the action of paramagnetic conductors, and considered the polarity which it acquires as the same with that of these conductors but I must now make clear a distinction which exists in my mind, with regard to *the polarity of a magnet* and the polarity, as I have called it, due to mere conduction This distinction has an important influence in the *case of iron* A permanent magnet has a polarity in itself, which is possessed also by its particles, and this polarity is essentially dependent upon the power which the magnet inherently possesses It, as well as the power which produces it, is of such a nature, that we cannot conceive a mere space void of matter to possess either the one or the other, whatever form that space may be supposed to have, or however strong the lines of magnetic force passing across it The polarity of a conductor is not necessarily of this kind, is not due to a determinate arrangement of the cause or source of the magnetic action which in its turn overrules and determines the special direction of the lines of force (2807) but is simply a consequence of the condensation or expansion of these lines of force, as the substance under consideration is more or less fitted to convey their influence onwards It is evidently a very different thing to originate such lines of power and *determine their direction* on the one hand, and only to assist or retard their progression without any reference to their direction on the other Speaking figuratively, the difference may be compared to that of a voltaic battery and the conducting wires or substances, which connect its extremities The stream of force passes through both, but it is the battery which originates it, and also determines its direction, the wire is only a better or worse conductor, however by variation of form or quality it may diffuse, condense, or vary the stream of power

2833 If this distinction be admitted we have to consider whether iron, when under the influence of lines of magnetic power, becomes a magnet and has its proper polarity, or is a mere paramagnetic conductor with conducting powers of the highest possible degree In the first place it would have the real polarity of the magnet in the second only that which I assign to oxygen and other conducting bodies To my mind the iron is a magnet It can be raised as a *source* of lines of magnetic power to an extreme degree of energy in the electro-magnet, and though when very soft, it usually loses nearly all this power upon the cessation of the electric current, yet such is not the case if the mass of metal forms a continuous circuit or ring, for then it can retain the force for hours and weeks together, and is evidently for the time an original source of power independent of any voltaic current. Hence I think that the iron under the influence of lines of magnetic power becomes a magnet, and though it then has the same kind of polarity, as to direction, as a mere paramagnetic conductor, subject to

the same lines of force, still with a great difference, for as the internal particles of iron become in a degree each a system producing magnetism, so their polarity is correlated and com-

mere conductor possesses

2834 It appears to me also as very probable that when iron, nickel and cobalt, are heated up to the respective temperatures at which they lose their wonderful degree of power (2347) and retain only so small a portion of it as to require the most sensible test to make it manifest (2343), *they then have passed into the condition* of paramagnetic conductors, have lost all ability to acquire that state of internal po-

(2819) It is also probable that in many states of combination these metals may take up the mere conducting state, for instance, that whilst in the *protoxide, iron may constitute a magnet*, in the peroxide it is only a conductor, and in this

any mere compression or divergence of these lines I have done so only that I might point with the more facility to facts and views that have heretofore been associated with some supposed polarity in the bodies which, whether

quence I have already asked *for such* liberty in the use of phrases (*lines of force, conducting power*, &c) (2149, 2797) as may, for the time,

phenomena described by us are, as I believe, due to a common cause, and are the same in

satisfy all that requires explanation in special results A magnecrystallic substance would then be one which in the crystallized

than in another

peared to me *as an anomaly in the supposition*, that a line of force could have reference indifferently to any part of a plane (2600) disap-

[1] I must refer here to the important paper by MM Tyndall and H Knoblauch *on this subject* in the *Philosophical Magazine* 1850 Vol XXXVII p 1 M F January 6 1851

[2] *Philosophical Magazine* 1849 Vol XXXIV, p 450

2839 But if such a view were correct, it would appear to follow that a diamagnetic body like bismuth ought to be less diamagnetic *when its magnecrystallic axis is parallel (as* nearly as may be) to the magnetic axis, than when it is perpendicular to it In the two positions it should be equivalent to two substances having different conducting powers for magnetism, and therefore, if submitted to the differential balance, ought to present differential phenomena, corresponding in kind to those of oxygen and nitrogen (2774), or phosphorus and bismuth, or any other two differing bodies Though I have given certain results on a former *occasion* which seemed to bear on this point (2551, 2552, 2553), they are not satisfactory *in the present state of our knowledge,* because the difference, if any, would be small (2552), and quickly hidden by the employment of a single pointed pole Other experiments, formerly described (2554-2561), would not show a small difference in diamagnetic force (though quite fitted for their intended purpose), because they were made with flat-faced poles, and a field nearly equal in magnetic power

2840 The differential torsion balance (2773) enabled me to return to this matter with better hopes of success A consistent group of bismuth crystals was selected (2457) and hung up on one side of the double cone core (2738), whilst a cylinder of flint-glass was opposed to it *on the other* The flint-glass was to be a standard of reference, and therefore neither its *place on the balance nor condition was altered* during the experiment The bismuth group was *placed* with its magnecrystallic axis horizontal, and so that it could be turned in a horizontal plane, *that* the axis might be at one time parallel to the magnetic axis (or lines of force), and at other times perpendicular to it, but without any alteration of the distance of its centre of gravity from the opposed glass cylinder. Hence, having either one position or the other, it could still be compared with the cylinder

2841 The magnecrystallic axis was first made parallel to the core or magnetic axis, the magnetic power developed, and when the diamagnetic bodies had taken their position of rest or stable equilibrium, the place of the balance lever was observed and recorded by means of a ray of light reflected from a mirror attached to it Then the bismuth was turned through 90°, *or until its magnecrystallic axis was perpendicular* to the axis of the double cone core, and now, when *the magnet was excited, the* place of the bismuth was found to be farther out from the core than before On being turned *through 90° more, so as to be in a position diametral* to the first (2461), its place was again *a little nearer to the magnet; and when in the* fourth position, which is diametral to the second, *then it was farther out Thus the crystallized* bismuth proved to be diamagnetic in different degrees, according with certain directions of its magnecrystallic axis, being more diamagnetic when this axis was perpendicular or transverse to the lines of magnetic force, than when it was parallel to them, and thus the expectation founded upon theoretical considerations (2839) was confirmed

2842 I tried to *obtain similar* results with a cube of calcareous spar (2597), for it is evident *that if its optic axis, being in a horizontal* plane, is first placed parallel to the magnetic axis and then perpendicular *to it, the body* ought to be more diamagnetic in the first position than in the second, inasmuch as the latter is the position which it takes up under the influence of its magnecrystallic or magneoptic condition I could not however obtain any distinct results partly because its power is in all respects very inferior to the bismuth, partly because of the present imperfection of my torsion balance and partly because of the size and shape of the calcareous spar *A* sphere or a cylinder, having the optic axis perpendicular to the axis of the cylinder, would be more cor*rect as forms of the substances to be tried.*

2843 *In concluding this part of the subject* relating to the magnetic conducting power, I will now *refer to some of the cases which I* think experimentally establish its *existence* in the two *subdivisions* of magnetic bodies (2805) The place and position of iron in a field of equal force (2810 2811) is no *doubt a result of* the extraordinary power which this body has of transmitting the magnetic force across the space which it occupies, whether the particles of the iron be considered as polar or not (2832), and therefore I accept the converse phenomena as to place and position of a diamagnetic body (2812, 2813) *as* proof that it has less power of transmitting the magnetic force than the space it occupies, and from that conclude that it conducts diamagnetically (2802)

2844 The separation of paramagnetic bodies in the equatorial direction is a proof of the manner in which, by their better conduction, they disturb the position of the lines of force in the medium around them (2831) The separation of two diamagnetic bodies, under the same

circumstances, is an equal proof of the manner in which, by difference of conducting power, they also disturb the disposition of the force (2831) The equatorial attraction of a paramagnetic and a diamagnetic body for each other, when they are in a medium, which in conducting power is between the two (2831) is a proof not only of conduction in both but also of their reverse condition in respect to each other and the medium

2845 The place of a crystal of bismuth, either nearer to or farther from the magnetic axis (2841), according as its magnecrystallic axis is parallel or perpendicular to the axial line, is also a case of th [illegible]

[illegible]

be inclined to deny. I will suppose that the above are enough to explain my meaning

2846 It is hardly necessary for me to say that [illegible]

[illegible] per, are below mere space in their ability to fa- [illegible]

[illegible]

of the manner in which lines of power are affected in bodies, and in part transmitted by them

§ 33 *Atmospheric Magnetism*[1]

¶ 1 *General Principles*

2847. It is to me an impossible thing to perceive, that two-ninths of the atmosphere by [illegible]

[illegible]

ature and condensation or rarefaction (2780), and at the same time subject to these physical changes in a high degree, by annual and diurnal variations, in its relation to the sun, without being persuaded that it must have much to do with the disposition of the magnetic forces upon the surface of the earth (2796), and may perhaps account for a large part of the annual, diurnal and irregular variations, for short periods, which are found to occur in relation to that power I cannot pretend to discuss this [illegible]

[illegible] 1849 XXV, p 510 [illegible]

and many others, who have wrought so zealously at terrestrial magnetism over the surface of the whole earth But as it has fallen to my lot to introduce certain fundamental physical facts, and as I have naturally thought much upon the general principles which tend to establish their relation to the magnetic actions of the atmosphere, I may be allowed to state these principles as well as I can, that others may be placed in possession of the subject If the principles are right, they will soon find their special application to magnetic phenomena as they occur at various parts of the globe

2848 The earth presents us with a spheroidal body, which, consisting of both paramagnetic and diamagnetic substances, disposed with much irregularity as regards its large divisions of earth and ocean, are also equally irregularly disposed and intermingled in its smaller portions Nevertheless it is, on the whole, a magnet, and, as far as we at this moment are concerned, an original source of that power And though we cannot conceive at present that all the particles of the earth contribute, as sources, to its magnetism, inasmuch as many of them are diamagnetic, and many non-conductors of electric currents, yet it is difficult to say that any large portion is not concerned in the production of the force hereafter it may be necessary, perhaps, to consider certain parts as mere conductors, i e, as parts merely permeated by the lines of force, originating elsewhere but for the present the whole may be assumed according to the theory of Gauss, as a mighty compound magnet

2849 The magnetic force of this great system is disposed with a certain degree of regularity We have the opportunity of recognising it only as it is exhibited in one shell or surface, which, being very irregular in form, is always the same to us, for we rarely, if ever pass out of it, or if we do, as in a balloon, only to an insensible extent This is the surface of the earth and water of our planet The magnetic lines of force which pass in or across this surface are made known to us, as respects their direction and intensity, by their action on small standard magnets, but their average course or their temporary variations below or above, i e, in the air above, or the earth beneath, are only dimly indicated by variations of the force at the surface of the earth, and these variations are so limited in their information, that they do not tell us whether the cause is above or below

2850 The lines of force issue from the earth in the northern and southern parts with different but corresponding degrees of inclination, and incline to and coalesce with each other over the equatorial parts Their general disposition is represented by the system, which emanates from a globe having within one or two short magnets adjusted in relation to the axis There seems reason to believe, from the analogy of such globes to the earth, that the lines of magnetic force which proceed from the earth return to it, but in their circuitous course they may extend through space to a distance of many diameters of the earth, to tens of thousands of miles. Messrs Gay-Lussac and Biot, in their ascent in a balloon perceived some indication of a diminution in the intensity of the magnetic force at a height of about four miles from the surface, but we shall shortly perceive that they might be at the time in the midst of influences sufficient to account for all the effect, so that none of it might be occasioned by removal from the earth as a magnet The increase of the intensity of the magnetic force, as we proceed from the equator towards the poles, accords with the idea of the enormous extension of this power

2851 These lines proceed through space with a certain degree of facility, of which a general idea may be gained from ordinary knowledge, or from experiments and observations formerly made (2787) Whether there are any circumstances which can affect their passage through mere space, and so cause variations in their condition, whether variations in what has been called the temperature of space could if they occurred, alter its power of transmitting the magnetic influence are questions which cannot be answered at present, although the latter does not seem to be entirely beyond the reach of experiment

2852 This space forms the great abyss into which such lines of force as we are able to take cognizance of by our observing instruments, which issue from the earth, proceed at least at all parts of the globe where there is a sensible dip But, as it were, between the earth and this space there is interposed the atmosphere, which, however considerable we may estimate it in height, is so small when compared to the size of the earth, or to the extent of space beyond it into which the lines of force pass, that the idea of its being a changeable, active something interposed between two systems far more extensive and steady in their nature and condition, will not lead to any serious error It is at the bottom of this atmosphere that we live and make all our inquiries, whether by observation or experiment

2853 The atmosphere consists as far as we are concerned at present of four volumes of nitrogen and one volume of oxygen, or by weight of three and a half parts of the former and one part of the latter These substances

tion[1] though they differ very strikingly in their constitution as regards this power

2854 *The nitrogen* of the air does not appear to be either paramagnetic or diamagnetic if removed from zero in either of these respects it is only to a very small extent (2783 2784) Whether dense or rare it has apparently the same relation to and equality with space as far as the present means of observation have proceeded As respects the other element of change namely, temperature I concluded from former imperfect experiments[2] that nitrogen

research repeated the experiments far more carefully

2855

battery served to raise the temperature of the gas around it The magnetic poles were raised were terminated by hemispheres of soft iron 0 76 of an inch in diameter and 0 2 of an inch apart and were covered by a glass shade resting upon a thick flat bed of vulcanized caoutchouc A tube passed through the bed rising up to the top of the shade by which any required gas could be introduced A very thin

mica plate and by melting the wax show where it came against the mica

2856 All acted exceedingly well *air* being in the glass shade When there was no magnetic

rent under natural circumstances but when the magnet was thrown into action then the wax on the mica remained unchanged the hot air being thrown so far away from the axial line and so cooled by its forcible mixture with the neighbouring air as to be unable to melt a spot of wax anywhere The moment the magnetic power was suspended the column of hot air rose vertically and regained its original position

2857 *Carbonic acid gas* was then sent into the shade until twice as much as the contents of the shade had passed through the pipe (2855) but as it was heavy and the common air could make its way out only at the bottom of the shade there was no doubt air mixed

er this the magnetic force caused much less deflection of the rising column Two volumes more of carbonic acid were sent through and now the hot current of gas rose so nearly vertical that there was scarcely any sensible difference of its place when the magnetic power was in full action or when it was entirely absent Hence I conclude that carbonic acid gas is very little affected in its diamagnetic relations by a difference of temperature equal to that between natural temperatures and a full red heat

2858 *Nitrogen* This gas was prepared by

contained no other oxygen or air than

[1] *Philosophical Magazine*, 1847 Vol. XXXI p. 416

[2] *Ibid* p 418

net was active, but this I attributed to a little

fected by such change of temperature

2859 I raised the French shade (2855) an inch for a moment, and then instantly placed it down again, and now, on making the magnet active and the coil hot, there was so much effect of dispersion of the gas within that the melted spot of wax appeared nearly an inch outside of the standard place, yet only a very small portion of air or of oxygen could have entered the vessel under these circumstances

dense or rare, or at high or low temperatures I formerly found that the diamagnetic metals,

gases

containing of the crystallized salt seventeen times the weight of the oxygen (2794) It becomes less paramagnetic, volume for volume

perature is *raised* the expansion consequent

and it may, perhaps, like them, rise by cooling to a very high state

2862 These relations it preserves when mingled with nitrogen in the air, as long as its physical and chemical conditions remain unchanged, but it is not irrelevant to remark, that every operation by which this active part of the atmosphere changes in its nature and passes into combinations, takes away its paramagnetic powers, whether the result be solid, liquid or gaseous

2863 Hence the atmosphere is, in common phrase a highly magnetic medium The air that stands upon every square foot of surface on the earth, is equivalent, in magnetic force to 8160 lbs of crystallized protosulphate of iron (2794, 2861) This medium is, by every change in its density, whether of the kind indicated by the barometer, or caused by the *presence or absence of the sun, changed in its* magnetic relations Further, every variation of temperature produces apparently its own

from the earth and causing variations, both in its intensity and direction, at the earth s surface Whether these changes are in the right direction and sufficient in quantity to supply a cause for the variations of the terrestrial magnetic power is the point now to be considered for the illustration of which I will endeavour to construct a type case and then apply it, as well as I can, to the natural facts

2864 Let us assume the existence of two globes of air distinct from the surrounding atmosphere, by a difference of temperature or by a difference of density the assumption is not too extravagant for an illustration, since Prout showed that there were masses of air larger or smaller, floating about in the atmosphere and singularly distinct from the surrounding parts by temperature and other circumstances Not to complicate the expression, we will leave out

present a field of equal magnetic force i e, having parallel lines of equal intensity of force passing across it

[1] *Philosophical Magazine* 1847 Vol XXXI p 417
[2] *Ibid*, p 406

atmosphere or space, and therefore more lines

be something like what is represented in Fig 7 (2874), and consequently the globe will be po-

regular and well known

2866 First as regards the *intensity*, which before was uniform (2864) If the intensity is to be considered as expressing the amount of force which passes through any given place,

that part and a diminution at some other parts as *b b*, from whence the influence of the power has been partly removed Hence supposing the normal condition to exist at *a* if a test of intensity were carried from *a* to P, it would gradually enter parts *b* and *c* in which

arrive at parts having the normal intensity and lastly, at parts P, having an intensity greater than the surrounding space as it went outwards on the opposite side of P, corresponding variations would occur in the reverse order

P, after which it would pass through places of less and less intensity, until at *p* it would again find the force in the normal state If the test, in being carried upwards be not taken along *the line of the dip*, then it will of course pass through variations like those described on the line *a* P, growing more and more in extent until the direction coincides with the line *a* P which is at right angles to the dip and where they are at a maximum Hence to pass upwards through such a globe of cold air in our latitude, where the dip is 70° nearly, and at the equator, where

it is 0°, would be a very different matter, and the necessary natural results of such a differ

direction To understand this point we have

else remained the same But being under natural circumstances surrounded by the atmosphere, which is a medium liable to variation in

with oxygen except by means of extremely delicate apparatus, but like effects are easily shown experimentally in selected analogous cases Thus let a thin small tube of flint-glass, about 1 inch long and ½ an inch in diameter, be filled with a saturated solution of protosulphate of iron and suspended horizontally by cocoon-silk (2279) between the poles of the electro-magnet, in a vessel which may either

lower gradations, for it returns with less and less force to its axial position when disturbed from it So the magnetic needle employed for measuring intensity or magnetic force (for the

curately, provided the condition of the sur-

concerns us in *atmospheric magnetism* and it is very important to know whether, when the magnet indicates an increased intensity of force, it is altogether due to a real increase of the amount of the power at its source as it comes to us from the earth, or in part to a change in the magnetic constitution of the space *around the magnet hitherto unknown to us*

2870 If what is now often indifferently called magnetic force or intensity have its results distinguished as of two kinds, namely, those of *quantity* and those of *tension*, then we shall more readily comprehend this matter At present a needle shows both these as magnetic

tity remains the same, and the quantity can be altered, yet the tension remain unaffected, the result by the needle will then be uncertain If

increase of magnetic power in the earth from

in tension in such proportions that the needle should show no change, or it might gain in quantity and lose in tension, and the needle still be entirely indifferent to the whole result

How *far* these uncertainties in its indication may affect the value of the observations made on the horizontal and vertical components of the earth's magnetic force as indications of that which they are expected to tell us, I do

amount of force at its source, the one of which is chiefly in the atmosphere and the other in

effects from each other

2872 Referring again to the model globe, *Fig 7* (2874), it appears to me, that *if a magnet be used as the intensity test, it will indicate a less intensity at P rather than a greater one, for the very reason that the conducting*

parts, especially those on the right and left, and even at *b* and *b*, where the power trans-

net to set with greater force, and so give an indication of increased intensity, and that also both within and equatorially without the globe

2873 If it be true that the changes of the medium (2869) can thus affect the magnet and that such changes can rise up to a sensible degree in the gases, then a magnet might make a different number of vibrations in a given time in oxygen and nitrogen gases of the same density, for they are very different in their magnetic relations It should make the greatest number in nitrogen, perhaps a delicate torsion

balance would be a still more sensible test of such a result but it is probable that the space around the needle should be large and it would be requisite to ascertain that the two media opposed equal mechanical resistance to the vibrating needle

2874 The variation of the *direction* caused by the typical globe (2864) might be oblique to the horizontal and vertical planes and consequently give results of declination and inclination either separately or together The direction would not vary in a central line parallel to the general dip of the surrounding space (*Fig* 7) Along another central line perpendicular to

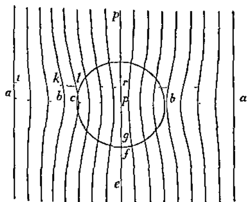


Fig 7

this (i e any line in the equatorial plane), a P there would also be no variation of the direction but in any other position there would be ...

then be conceived as travelling in a circle round the ...

sidered they will be equal in amount but in the reverse direction so that the magnetic needle ...

the apex of which is above.

2876 So the dip would vary in such a globe of air in every azimuth and it would also vary in opposite directions in the upper and lower parts of the globe and of the affected surrounding space

2877 If we assume the existence of another typical globe of air (2864) having a higher temperature than the surrounding atmosphere then its condition will be that of a diamagnetic conductor, and will be represented by *Fig* 9

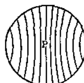


Fig 8

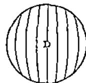


Fig 9

mer globe but in the contrary order As re- ...

globe of air and the representative magnet

2878 In endeavouring to proceed from these ... of simple cases

and the earth we have to consider that though

... different from

ent to that of the approach of a body of cold air from the east, will be produced, which will increase and then diminish, and be followed by another series of effects as the sun rises again and brings warm air with him

2879 The atmosphere diminishes in density upwards, and that diminution will affect the transmission of the magnetic force, but as far as it is constant, the effect produced by it will be constant too The portion of the atmosphere which lies under the heating influence of the sun, as compared to its depth, will more resemble a slice of air wrapped round the earth than a globe Still the inflection of the lines of force, both above and below this stratum, will occur, extending into space above and into the earth beneath (2848), according to the known influence of magnetic power and its perfectly definite character (2809) We are placed at the bottom of this layer of air, but as the atmosphere is denser there than higher up, and is also in many cases more affected there by changes of temperature, we are probably in a position where the inflections and variations due to the assumed causes exist in a considerable degree

2880 *There are innumerable circumstances* that will break up, more or less, any general or average arrangement of the air temperature. For instance, the diversity of sea and land causes variations of temperature differently in different times of the year, and the extent to which this goes may be learned from the beautiful isothermal charts of Dove, now fortunately to be had in this country[1] These variations may be expected to give, not merely differences in the regularity, direction and degree of magnetic variation but because of vicinity, differences so large as to be manifold greater than the mean difference for a given short period, and they may also cause irregularities in the times of their occurrence

2881 On considering the probable results of the magnetic action of the atmosphere, it appears to me that if the terrestrial magnetic force could be freed from all periodical and small perturbations, and its disposition ascertained for any given time, it might still include certain effects constituting a part of atmospheric magnetism For instance, there is more air, by weight, over a given portion of the surface of the earth at latitudes from 24° to 34°, than there is either at higher latitudes or at the equator, and that should cause a difference from the disposition of the lines of force which would exist if there were equality in that respect, or if the atmosphere were away Again, the temperature of the air is greater at the equatorial parts than in latitudes north or south of it, and as elevation of temperature diminishes the conducting power for magnetism, so the proportion of force passing through these parts ought to be less, and that passing through the colder parts greater, than if the temperature of the air were at the same mean degree over the whole surface of the globe, or than if the air were away Again, there is a greater difference in range of temperature of the air at the equator as we rise upwards than in other parts and hence the lower part is not so good a conductor proportionately to the upper part, or to space, as elsewhere, where the difference is not so great, the magnetic power, therefore, should be in some degree weakened there, the lines of force being diverted, more or less from the warm air and thrown into other parts, as the cooler atmosphere and space above, or the earth beneath according to the principles before explained (2808, 2821, 2877).

2882 *The result of annual variation* that may be expected from the magnetic constitution and condition of the atmosphere seems to me to be of the following kind Assuming that the axis of rotation of the earth was perpendicular to the plane of its orbit round the sun, and dismissing for the present other causes of magnetic variation than those due to the atmosphere, the two hemispheres of the earth, and the portions of air covering them, would be affected and warmed alike by the sun, or at least would come into a constant relative state, dependent upon the arrangement of land and water, and the lines of magnetic force having taken up their position under the influence of the great dominant causes, whatever they may be, would not be altered by any annual change due to the atmosphere, since the daily mean of the atmospheric effect in a given place would at all parts of the year be alike Under such circumstances the intensity and direction of the magnetic forces might be considered constant, presuming no sensible change to take place by the difference in distance from the sun which would occur in different parts of the orbit and, as regards the two magnetic hemispheres, each would be the equivalent of and equal to the other, and they may for the time be considered in their mean or normal state

2883 But as the axis of the earth's rotation is inclined 23° 28′ to the plane of the ecliptic,

[1] *Report of the British Association* 1848 *Reports*, p 85

the two hemispheres will become alternately warmer and colder than each other, and then a variation in the magnetic condition may arise The air of the cooled hemisphere will conduct magnetic influence more freely than if in the mean state, and the lines of force passing through it will increase in amount whilst in the other hemisphere the warmed air will conduct with less readiness than before and the intensity will diminish In addition to this effect of temperature there ought to be another due to the increase of the ponderable portion of the air in the cooled hemisphere, consequent upon its contraction and the coincident expansion of the air in the warmer half, both of which circumstances tend to increase the variation in power of the two hemispheres from the normal state Then as the earth rolls on in its annual journey, that which at one time was the cooler becomes the warmer hemisphere, and conse

magnetic condition from less to more intense

2884 As the sum of the magnetic forces

to that take place The condition of the two hemispheres under this view may be conceived

diffused and diminished intensity in the south and in summer the reverse

2885 In respect to *direction*, alterations may also be anticipated In the first place, and as

isphere and increase towards the magnetic

changing temperatures so a cause of difference in direction will here arise

2886 Again it may be that as oxygen is

in combination with the holding power of the earth (2907) may even cause a change the reverse of that expected above in lower latitudes If in our winter the lines of force were to close together in the polar parts and to open out in

and the space above our atmosphere are un

whole of a hemisphere *is affected at once* in the same direction by change of temperature it will *not be affected alike, but differently in different latitudes*, because of the difference in amount of that change

2888 The difference of land and water (2880) will still further break up any expected uni

that place

2889 As the annual changes of temperature are less at the equator than in parts more north

or south, so there, probably, little or no annual variation would occur none indeed as regards the varying temperature or expansion of the air, but only that portion which is consequent upon the alternate changes of the parts on its opposite sides (2881)

2890 Another effect, which may be considered as an annual variation, but which is connected with the diurnal change, may be expected As the daily changes in temperature of the atmosphere influential upon a given place in north or south medium latitudes, are greater in extent in summer than in winter, so the corresponding magnetic variations may be expected to vary also, being larger in the northern hemisphere, when the sun is on the north side of the equator, and less when he is present in the southern hemisphere, and producing like correspondent change there

2891 From a most important investigation by Colonel Sabine[1] founded on the results of observations at Toronto and Hobarton the facts appear to be that the magnetic intensity is greater in both hemispheres in those months which are winter in the northern hemisphere, and summer in the southern Similar results are greatly wanted for other localities and would show whether the different disposition of land and sea has anything to do with the question, or whether the results at Toronto and Hobarton are true exponents of hemispherical effects Assuming Toronto and Hobarton as being such exponents, the dip in both hemispheres is greater (i e, greater north dip at Toronto and south dip at Hobarton) in those months which are winter in the northern, and summer in the southern hemisphere Whether there is any *annual* variation of the dip or total force in the equatorial parts of the globe is very important to determine. It would be well worth while to take up a station for the express purpose, the instruments are very simple, and the observations would require only a single observer They are described in the paper referred to Unfortunately such observations are not even made in Great Britain

2892 The manner in which the diurnal variation may be produced or affected by the action of the sun on our atmosphere as the earth revolves in its beams has been already generally referred to The whole portion of atmosphere exposed to the sun receives power to refract the lines of magnetic force which traverse it, and the whole of that which covers the darker hemisphere assumes an equally altered, but contrary state relative to the mean condition of the air It is as if the earth were inclosed within two enormous magnetic lenses competent to affect the direction of the lines of force passing through them

2893 I have already said that the action of the atmosphere thus affected might in some degree be compared at night-time to that of an enormous diffuse and very feeble ordinary magnet having the position that it would naturally take according to the line of dip passing over us from east to west, and including us for the time within its influence in the day time the action would be like that of the similar journey, not of a corresponding magnet reversed in direction, but of a corresponding globe of diamagnetic matter (2821) Assuming the maximum heat and cold to occur at mid day and midnight, we might expect that the maximum effects would also occur near those periods as regards the variations of intensity (2824, 2866), for other things being the same, the central parts of the heated and cooled masses are those where the difference of intensity should be greatest

2894 It might be expected that this variation in the *intensity* would be greatest at those parts of the globe over which the sun passes vertically, or nearly so but that may depend upon two circumstances at least, first, whether the difference in the day and night temperature is greater there than at other places, because the extent of the variation may be dependent in part upon that difference, and next, whether the amount of effect to be expected is the same for the same difference in number of degrees of temperature at every part of the scale (2886) If the conducting power of oxygen (2800) should be found by future experimental measurements (2960) to increase in a greater proportion for a fall of a given number of degrees at lower temperature than at high ones (including the effect of contraction for that fall [2861]) then it may be that parts more distant from the sun will be more affected than those under it or if the contrary be the case, less affected than otherwise would be expected

2895 With regard to the daily variations, as respects the *direction* of the lines of terrestrial magnetic force, or the inclination and declination of the magnetic needle, the principles of the changes that may be expected to occur

[1] On the means adopted for determining the Absolute Values, Secular Change and Annual Variation of the Magnetic Force *Philosophical Transactions* 1850, p 201

have been already referred to (2879) and it remains for me to compare these expectations with a few simple cases of observation in such a general manner as will tend to show whether the *direction* of action is both in theory and

variation namely the effect of the sun and air as the luminary arrives at and passes over the meridian

2896 Profiting by the last volume which has issued from the powerful mind and careful hands of Colonel Sabine [1] I will take the case of Hobarton The observatory there is in latitude 42° 52 5 south and longitude 147° 27 5 east of Greenwich The absolute declinat on is 9° 60 8 east and the dip is 70° 39 south In order to have the place of the sun and the time of maximum and minimum temperatures at hand I have transferred the mean temperature for January (summer) for seven years 1841 48 and the mean temperature for June (winter) for the same period corresponding to every

Fahr and the two curves still lower down the mean hourly temperature for summer and win

tinguished b

west about 21 o clock. Being at the extreme west at the latter hour it passes through the full range of variation or to the extreme east in five hours or by 2 o clock and then requires the remaining nineteen hours to return to the utmost west The maximum east and west declination is at 2 and 21 o clock for summer and

or a little before noon About 2 o clock the needle is arrested and after that time returns west following the sun It will be proper to state that the north end of the needle the motion of which has just been described is the

dle appears to be far more powerful and more concentrated in time when the sun is present than when he is away In this there is accordance between the time of the effect and the time when the sun could exert most influence on those magnetic conditions of the atmosphere which are for the present supposed to govern that effect

2899 It will be seen by examination of *Fig 10* that the time of maximum temperature is not when the sun is on the meridian but two

tion (2890) The minimum temperature in winter is later than in summer and the extreme western declination of the needle is also later at the same period

2900 The varying *direction* of the magnetic

[1] *Magnetical and Meteorological Observations* Hobarton Vol I 1850

diminishes until about 3 o'clock, it then continues nearly the same in summer, when the variation is greatest until 18 or 19 o'clock, from that time it increases until about 22 o'clock, and is nearly a maximum from thence till noon Hence it will be understood, that the inclination is generally greatest during the rapid journey of the north end of the needle from west to east between 21 and 2 o clock and least in the other or prolonged half of the journey, and though this is partly broken up in the night effect to be considered hereafter, still as a general result it always appears

2901 All this may be roughly represented by *Fig 11* (2909) in which E W represents the *path of the sun between the tropics as he comes* up with the hours 21^h 22^h, &c, in his daily journey, and *c* the path described by the north or upper end of the needle, freely suspended at Hobarton, and therefore showing both declination *and inclination, i e the whole direction* Looking down upon such a needle, its upper end will take the course indicated by the arrow, and its position at any given hour is shown sufficiently by the leading lines

2902 This relation of the motion of the needle to that of the sun has long been known it has great significance in relation to my hypothesis of the physical cause of these variations As regards the part of the ar[illegible] considering [illegible] or [illegible] of [illegible] ust driving that en[illegible] towards 19 o'clock the tendency westward diminishes but the tendency south increases At 21 o clock, the increase in the sun's power, acting not directly from the sun but from a region in the atmosphere beneath it, is not sufficient to compensate for his more unfavourable position the earth's force brings the needle back as regards declination, and then it passes eastwards but the southerly motion or inclination still increases, about 24 o clock, or noon *the sun is as to east or west* declination indifferent, but powerful in southern action making the inclination then, or soon after, a maximum Then as the sun goes west of the needle, its power in driving the pole behind it eastward will increase for a time, whilst the power *producing* inclination will diminish, until at 2 or 3 o'clock the earth's force will regain preponderance as the sun's power diminishes by distance, and the needle will return towards its least dip and mean inclination

2903 *All this may be represented* experimentally by carrying a magnetic pole north of the dipping needle, so as to represent the place of the sun heated air *to Hobarton*, provided that pole be of the same kind as the north or upper pole of the needle I have already stated (2863, 2877), that when a portion of air is heated in a field of magnetic power, it loses in magnetic conduction power, and if in association with air less heated deflects the lines, assuming the state which I have distinguished as that of diamagnetic conduction polarity, then presenting the very polarity, or rather the very inflection of the lines of force, which would affect the needle, as it is affected As the sun rises and passes north of such a place as Hobarton, the atmosphere under his coming influence becomes more and more heated and expanded, and referring to the model globes of air (2864, 2877), it is as if such a warm mass passed with the sun through all the regions of the equator, extending also far north and south *of it, and, having Hobarton within its influ*ence, produced the effects there observed

2904 In such a view one sees a reason for the short time occupied in the return of the needle from west to east as the sun passes immediately *over its meridian*, and for the long time during which it is passing from east to west as the influence of the sun is slowly withdrawn, and then again slowly renewed during the remaining part of his journey, exception being made for the present of the paramagnetic effects due to cold

2905 I will now consider the Toronto case of diurnal variation as it is presented to us in the volume of magnetical observations, issuing from the same authority and hands as the former volume,[1] and also in further observations down to 1848, sent to me by the kindness of Colonel Sabine The position of the observatory is in lat 43° 39′ 35″ N and long 79° 21′ 30″ W The absolute declination is 1° 21′ 3″ W, and the mean or absolute dip is 75° 15′ N, so that as regards Hobarton it is on the other side of the *equator, and nearly on the other side of the* world The results for the months of June and December are placed in a diagram corresponding to that for Hobarton (2896), employing the Toronto time for the hours, *Fig 12*

2906 The north end of the needle is that universally referred to in speaking of the declination, its course at Toronto, during the immediate sun effect is as follows Having gradually moved east from 16^h, it is at extreme east at 20 o'clock, and then returns from the east to

[1] *Magnetical and Meteorological Observations* Toronto 1840 1841 1842 Sabine

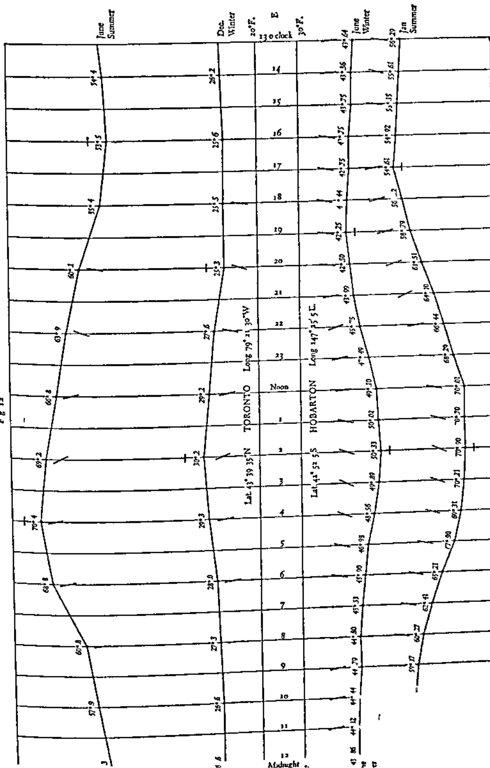

June Summer
Dec. Winter
June Winter
Jan Summer
23 o clock
Noon
Midnight
TORONTO
Lat. 43° 39 35 N
Long 79° 21 30 W
HOBARTON
Lat 42° 52 5 S
Long 147° 25 5 E

Fig 10

extreme west in six hours, after which it moves eastward from the sun But if we convert this into the motion of the equatorial extremity of the needle, for that is the *upper* end if the needle be free, and concerns us most in the comparison with Hobarton, then it will be seen that this end is most west at 19^h or 20^h and leaving that position at that hour, it travels quickly eastward, passing through the full range of variation or to extreme east in six hours, or until 2^h, and then returns, following the sun

2907 Looking at these results, I might repeat the words used in illustration of the Hobarton effects, but for the sake of brevity will simply refer to them As before, the amount of variation in the declination is in summer double what it is in winter The difference of temperature is three times greater The extreme west and east declination is both in summer and winter at 20 and at 2 o clock so that the magnet holds to the time in both seasons, but the maxima and minima of cold, as shown before, vary in the two seasons, for the former is at 4 o'clock in summer and 2 in winter, whilst the latter is at 16 o'clock in summer, and 20 o clock in winter But this is a variation with consistency, *for it will be seen by a moment s inspection*, that in winter the maximum of heat has *moved towards the time of most powerful action* in the one direction, and the minimum has moved towards it in the other The passage of the sun, therefore, over the meridian, and the period of rapid motion of the needle from west to east still coincide.

2908 The other element of direction is the inclination Its variation is very small, but changes thus A principal maximum dip occurs at 22 o'clock, and the extreme minimum dip at 4 o'clock

2909 So all the effects may again be generally represented by an ellipse (*Fig 13*) as they were for Hobarton and I may refer to the words then used, substituting Toronto for Hobarton and north for south (2901) As the sun *comes up from the east in his course between* the two places, he drives, by the altered atmosphere beneath him, the upper ends of their needles before him, and outwards from the line of his path, as if he were a north pole to the Hobarton magnet and a south pole to the Toronto magnet By 22 o'clock, the earth's force, and the action of the air due to the sun's position, permit a return to the east, though the inclination for a time increases (2902), both swing rapidly round from west to east as he *passes over the meridian and then* having attained their maximum position eastward, soon *follow after* him under the influence of the earth s force, less and less counteracted by the retreating sun So striking is the similarity between Hobarton and Toronto, that Colonel Sabine has already especially distinguished and described it [1] and has shown, that, laying down the direction of motion in both cases by curves, and bringing the two curves together by their faces, they coincide almost exactly, with this *single difference that the Hobarton* changes precede those at Toronto by an hour, or rather *more, of local time*

Fig 13

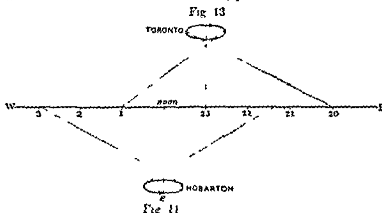


Fig 11

2910 We cannot represent this day effect experimentally upon two such needles as those at Hobarton and Toronto by *one* pole of a magnet, though we can do it with each separately with different poles but we see at once from the hypothesis, the reason why the sun acts in this manner (2877), and how it is that the region of influential atmosphere that accompanies him in his journey round the globe, acts with

[1] *Hobarton Magnetical Observations* 1850 p 35

one effect in the northern latitude and another in southern positions (2903) The reasons also for the short time of the day journey and the lengthened period of the night return (2904), are manifest. The occurrence of disturbances or secondary waves of power in the night-time, and the condition both of the chief variation

we have to consider for the purpose of a ready comparison with the sun's observed day action (2906), I will describe those parts of its course and place for Greenwich time which concern us now. Moving westward before 19^h and 20^h, it then returns towards the east, and in six

needle therefore is more upright at the former time and less at the latter, and as the latter

lar closed curve, which the ellipse for Toronto, *Fig 13* (2909), may generally represent, it passes from east to west slowly during the night

upper end of the needle is in the morning at extreme west, about 20 to 22 o'clock, and at extreme east about 2 o'clock, it then returns slowly west, with the night action as in former cases, regaining extreme west at 20 to 22 o'clock This is exactly the same movement for declination, in relation to the place of the sun, as for the former localities I have not the variation of the dip, but theory would lead one to conclude that it is greatest between 22 and 2 o'clock, and least in the evening and night-

time. The total amount of declination variation is greatest in summer, as before, being 9′ 87 in July and only 4′ in December The

Fahr The shortest period between the extreme temperature, including therefore the quickest change of temperature, is from 16 or 18 to 2 o'clock, and consequently includes noon All

five months, but as the position is in a high latitude and may be important for future consid-

amount of declination variation is very great, being in October 21′ 32, in November 10′ 8, in December 9′ 78, in January 16′ 29, and in February 14′ 87

2914 *Fort Simpson* Latitude 61° 52′ N,

west in regard to noon, about 19^h and 20^h for

night.

2916 Thus these cases, which, including the chief feature of diurnal variation and sun action, *were selected as a first and trial-test of* the hypothesis, join their evidence together, as far as they go, in favour of that view which I *am offering for their cause, nor have I yet found* any instance of even an apparent contradiction in regard to the sun action They assist the mind greatly in forming a precise notion of the manner in which the influence of the sun and air is supposed to act, not only in similar cases, but in respect of other consequences, i e in all that properly comes under the term of *atmospheric magnetism, I will therefore* now restate more particularly the principles which, according to the hypothesis, govern them, in hopes that I may be fortunate enough to assist in developing by degrees the *true physical cause of the magnetic variations in question*

2917 Space, void of matter, admits of the transmission of the magnetic force through it *(2787, 2851) Paramagnetic and diamagnetic* bodies either increase or diminish the degree in which the transmission takes place (2789) This, their influence, I have expressed, for the time, by the phrase of *magnetic conducting power*, and I think have given sufficient first experimental evidence of the existence of the power and its effects in disturbing the lines of magnetic *force* (2843) The *atmosphere is*, by the oxygen it contains (2861, 2863), a paramagnetic medium, and has its conducting force greatly diminished by elevation of temperature (2856) and by rarefaction (2782, 2783), as has *also been fully proved by experiment The sun* is an agent which both heats and rarefies the atmosphere, and in its diurnal course, the place of greatest heat and rarefaction must, speaking generally, be beneath it The irregularities in the *condition of the earth's surface and other* causes do produce local departures from an exact relation of place, but they probably *disappear partly, if not altogether,* in the upper regions of the air

2918 *Assuming that the air under the sun* is most changed magnetically, and confining the attention to a spot where the sun is vertical, *for the purpose of considering* the condition of the atmosphere there and at other parts in relation to it, the supposition of a globe of air over the spot will of course find no fit application (2877) We are first to suppose the sun far *away and the atmosphere in a mean state* as to temperature, and then consider the sun as present in the meridian of a given place, and it is *the degree of alteration* in temperature and expansion of the air beneath and around the place of the sun, and the manner in which the change comes on and passes away, which concern us In relation to the surface of the earth, that alteration will be greatest somewhere *beneath the sun, and will diminish in every direction* around, becoming nearly nothing as to direct action at that part or circle of the earth where the sun's rays are tangent In relation to elevation, it is a question yet whether the effect is greatest in amount at the surface, diminishing upwards As regards the atmosphere, it must of course end with it, though as *respects space itself (2851), a reservation-thought* may arise With regard to any alteration occasioned by the sun's influence in the opposite hemisphere, though there is none produced directly, yet indirectly there is that due to the *falling* of the temperature of the air, *from the* condition to which the sun, whilst above the horizon, had brought it This change must be *more tardy, irregular and disturbed,* by local and other circumstances, than the opposite alterations produced by the direct influence of the luminary, and is that which occasions, by the hypothesis, the second maximum or minimum or other recurring night actions, *made* manifest by the needle in the hours when the sun is away

2919 The *lines of force* which issue from a magnet are, as it were, located and fixed by their roots in a way well understood experimentally by those who have worked upon this subject In the same manner the lines which *issue from the earth more or less suddenly*, according to the amount of inclination, are held beneath by a force of location, and because *of* the unchanging action of the earth in respect to atmospheric effect, are restrained more *or less from alteration beneath during the chang*ing action of the atmosphere. This fixation in the earth is a chief cause of certain peculiarities in the atmospheric phenomena as we observe them, and is productive of that rotation of the line of force about the mean position which we have already considered during the sun swing, and shall meet with again under the *action of cold air* This condition of fixation at the lower parts of the lines of force occurs at every station where there is any dip at all, *and* gives for each the point of convergence round which the motion of the upper end of the needle takes place (2909, 2932)

2920 So the atmosphere, under the influence of the sun, lies upon the earth *altered most* at the part beneath the luminary It has re-

ceived power to affect the lines of magnetic force differently to the manner in which it affected them in the sun's absence It has become a great magnetic lens, able *to refract the lines*,

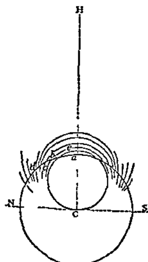


Fig 14

because of its being a worse magnetic conduc-

ic polarity If, therefore, for the sake of sim-

magnetic poles, and the different curves cutting the outline of the circle will sufficiently

therefore taking up its position in the line of force, ought not, if placed at this spot, to be altered in its position It ought to show perhaps a diminution of magnetic force transmitted through that spot, but, for the reason before given (2868), *I conclude it would indicate a* greater intensity, the increased power thrown upon it through the diminution of the conducting power of the air in that place causing it to *act as a more powerful needle*

continue to have the same curvature as before, for towards and in the earth, where they have their origin, they are restrained more or less from altering by the unchanging action of the earth (2919), whilst at their more advanced parts, as at *c*, they enter into portions of the atmosphere which are nearer to the most in-

than can happen in the earth

fest that whatever happens on one side of the place of the *sun and magnetic equator, when*, as in our supposition (2920), they coincide, will happen on the other

2023 The case may be more simply stated, *for the facility of recollection*, by saying that

which the north and south dip are simultaneously affected and increased

of a globe round which a magnetic lens, such as I have endeavoured to describe, is continually revolving

2925 Instead of assuming that the sun is at H, let us suppose that we are looking at the diagram in a vertical position and towards the east, *the sun coming up from the east and passing over our heads, and bringing with it that* condition of our atmosphere which is the cause of the change As it does so, all the magnetic curves would rise, the inclination would increase at *b*, *d*, and every place where there was any previously, in opposite directions on the two sides of *a* this would go on until the sun was in the zenith, and then as it passed away and sink behind us, the lines would draw in again and the dip diminish to what it was at first The maximum of dip would be when the sun was near the zenith, and the minimum when he was quite away

2926. But if the resultant of force be above in the atmosphere (2937), which is by far the most probable, *as it is the whole atmosphere which acts by heat diamagnetically*, then the results would be modified for if over *a*, the lines of force might be *depressed*, and any inclination there would be diminished, at *b* it might not for the moment be affected whilst in higher latitudes it would be increased, according as the line of force from the resultant *in the atmosphere, wherever that might be*, fell outside of the angle formed by the inclination with the horizon of a given place or within it St Helena the Cape of Good Hope, and Hobarton, furnish instances of the three cases

2927 At the same time the total force would undergo a change in its amount that transmitted *through a given space would be least* when the sun was in the zenith, and most when he was away (2863) The total variation in the force should be greatest at *a* and diminish from thence towards north and south The daily variations of the inclination are so imperfectly known to us at present that we cannot *say how far the natural changes will accord* with these expected variations, but as far as the observations go they agree with the theory

2928 If the sun, instead of being over the equator, is at a tropic and so vertical, for instance, over *b*, then the effects will be modified, and the resultant still being assumed as above, the lines of force which before were *not affected*, may be expected *to descend* and lessen the inclination, whilst other lines in higher latitudes, which before were increased in inclination, may now be but little affected, and other lines in still higher latitudes have, as before their inclination, increased On the other side of the equator, the tendency of the lines would be to increase in inclination

2929 Proceeding to that part of the expected change of position of the free needle which produces *variations of declination*, let *e r* in *Fig 15 represent the sun's path in the equator, and t c, t' c'* the same at the tropics, let *m r* be a magnetic meridian and *a a'*, *s s'*, *o o'* places of equal north and south inclination on opposite sides of the equator The curves of magnetic force seen in front in *Fig 14*, are now in the

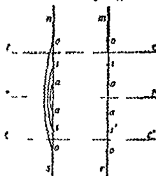


Fig 15

plane of the magnetic meridian, but may be considered as rising on opposite sides of the equator and coalescing over it *If the air on all sides were in its mean condition and the sun* entirely away, these curves would be in the vertical plane *m r*, or if the sun near midday was so placed that the resultant of the heated and changed atmosphere was in the meridian *m r*, though effects of inclination would occur (2922), still the curves would remain in the same vertical plane *But if the resultant were either to* the east or the west of *m r*, variations of declination would be produced For suppose the sun to be advancing from the east or *r* because it gives the air a diamagnetic condition, the lines of force would tend to expand (2877), and therefore move westward, as represented in the meridian *n s* and the deflection *caused thereby would be greatest upon the surface of the earth* because it is there that the curves as they enter the earth are held and restrained in respect to their normal position (2910) As the warmed atmosphere came on, the western deflection would increase to a certain extent, *and then diminish to nothing when the resultant* was in the meridian, but as the latter passed on, the deflection would grow up on the eastern side of *n s*, and after attaining a maximum, would diminish and cease as the warm air retreated

2930 If the sun's path was in the northern tropic, *i e* and the resultant in the atmosphere therefore to the north of the stations *a* or *i*, though that would make a difference in the amount of the declination variation, it would not alter its *direction* for still the curves *a a'* and *i i* would bear to the west as the sun came up, and would be on the meridian when the resultant was there also There would be more effect produced at *i* than at *i'*, but the contrary character of the dip, in respect to the sun s place, would not alter the direction of the declination variation

2931 A cold region of air acting as at the coming on of night, upon the lines of magnetic force of the earth, would by virtue of its para

from the earth at all places upon its surface where there is any dip, will by the hypothesis, under the daily influence of the sun, describe by their ascending parts a closed curve or irregular cone, the apex of which is below As a fact this result is perfectly well known but its accordance with the hypothesis is important for the latter The mean position of the free needle will be in the axis of this curve or cone,

That th

the lines It is not necessary even that the lines, which are immediately affected in direction by the altered air should be those about the needle, but may be very distant The whole of the magnetic lines about the earth are held by their mutual tension in one connected sensitive system which has no sluggishness anywhere, but feels in every part a change in any one particular place There may be and is continually, a

the magnetic power around a given locality fastens itself even to the antipodes and it shows for each place every variation in their amount or disposition whether that occurs near

position (exclusive of secular changes), and so bring them and the needle back from their disturbed to their normal state Hence whilst considering the causes which disturb either the declination or the inclination arises the importance of keeping in mind the mean position or place of the needle (2932) and not merely the direction in which it is moving

2936 So the well known action of the sun on the needle is by my hypothesis very indirect, the sun at a given place affects the atmosphere, the atmosphere affects the direction of the lines of force the lines of force there affect those at any distance and these affect the needles

shown by the manner in which the greatest action precedes, in some degree, the sun, as at Hobarton and Toronto, and other places by different amounts of time, neither the time when the sun is on the meridian, nor the time when the observed temperature is highest (for that is after the sun), is the time of greatest action, but one before either of these periods The changes in the temperature of the air produced by the sun, will not take place below and above at the same time The upper regions of the atmosphere over a given spot are affected by the sun at his rising and afterwards, before the air below is heated, and therefore the effect from above would be expected to precede that below The temperature observed on the earth does not show us, for the same time, the course of the changes above, and may be a very imperfect indication of them The maximum temperature below is often two, three, or four hours after the sun, whereas, whatever heat the sun gives by his rays directly to the atmosphere, must be acquired far more rapidly than that. It is very probable, and almost certain, that at 4 or 5 o clock A M in the summer months the upper regions may be rising in temperature, whilst on the surface of the earth, through radiation and other causes, it is falling The well known effect of cold just before sunrise in some parts of India, and even in our country, is in favour of such a supposition We must remember that it is not the absolute temperature of the air at any spot that renders it influential in producing magnetic variations, but the *differences* of temperature between it and surrounding regions. Though the upper regions be colder than the lower, their changes may be as great or greater, they happen at a range of temperature which is probably more influential than a higher range (2967), and, what is of importance, they occur more quickly and directly upon the presence of the sun The quantity of heat which the atmosphere can take directly from the sun's rays, is indicated by the different proportions we receive from him when he is either vertical or oblique to us, and so sending his beams through less or more air, and when he has departed, the upper parts of the air are far more favourably circumstanced for rapid cooling by radiation than the portions below So that the final changes may be as great or greater than below, and we may learn little of them, or their order, or time, by observations of temperature at the earth's surface In addition therefore to observations of magnetic effect, as depression of the lines of force at St Helena, &c, there are apparently reasons deducible from physical causes, why the chief seat of action should be above in the atmosphere

2938 In the midday effect the upper end of the needle passes the mean position (2935) on its return to the east generally before the sun passes the meridian going westward At Toronto it is about an hour in advance, at St. Helena and Washington an hour and a half, at Greenwich and Petersburgh two hours, at Hobarton and the Cape of Good Hope the passage is about noon Such results appear to indicate that the place of maximum action is in advance of the sun, and it probably is so in some degree, but not so much as at first may be supposed, as will appear, I think, from the following considerations

2939 The precession of the time of maximum action may depend in part upon some such condition as the following As the sun advances towards and passes over a meridian, the air is first raised in temperature and then allowed to fall and these actions produce the differences in different places on which the magnetic variations depend But they depend also upon the *suddenness* with which or the vicinity at which these differences occur Thus two masses of air, having equal differences of temperature, will affect the lines of force more if they be near together, and to the needle, than if they be far apart And again, if a body of air were of a certain low temperature at one part, and, proceeding horizontally, were to increase rapidly to a certain high temperature and then diminish slowly to the first low temperature, such a body passing across a set of lines of magnetic force would affect them in opposite directions at the fore and after part, but it would affect them most on the rapidly altering side

2940 Now the air as heated by the sun must be in this condition According to analogy with solid and liquid bodies, being exposed to heat and then withdrawn, the changes of temperature that it would undergo would be more rapid in the elevation than in the falling, and so the changes in the preceding would be more rapid than in the following parts To this would be added the effect of the atmosphere warmed by the earth, for as that is slower in attaining heat, as is shown by the time of maximum temperature, so its effects being gradually communicated to the air above, as the sun passed away, would tend to retard its fall and enlarge the difference already spoken of Applying these considerations to the natural case, the strong-

mean condition of the needle for the whole change would be in advance of that body

2942 There is another circumstance which importantly influences the *times* of the passages of the declination variation If two places north and south of the equator have equal dip and contrary declinations, i e, if both their upper ends point east or west, then the effects ought to correspond and form a pair But if both have east or west declination according to the usual mode of marking this effect by the north end of the magnet then the variations already described

and approaches, the needles *a* and *b* (Fig 16)

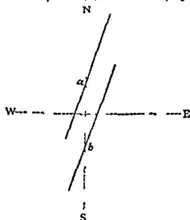


Fig 16

will most probably be affected together, but, as he draws nigh, if the places have eastern declination, the one that is south will be soonest affected and for the time most strongly, but

of both were westerly, then the north needle would precede the south

2943 The hypothesis advanced, besides

also agree in the *amount* of force required for the observed declinations at given hours I have endeavoured to obtain experimental evidence of the difference of action of oxygen and nitrogen on needles subjected to the earth s power but have not yet succeeded This however is

use an apparatus of extreme and almost infinite sensibility, but from what I have seen of oxygen when compared at different degrees of dilution (2780), or at different temperatures (2861) I am led to believe that the effects on it produced by the sun in the atmosphere will ultimately be found competent to produce these variations

tions and the extent of their influence

shown by the photographic records of Greenwich and Toronto The volume of *Greenwich Observations* for 1847 contains a photographic record of the declination changes I-l- y 18–19, 1849 Between [illegible]
[illegible]
or [illegible]
tin [illegible] variation for the
sar [illegible] time is 1 95 in two hours, or at the rate of 1 second for each minute of time, so that the irregular variation (which may be considered as a local variation in respect to the sun's power for the time) is sixty times that due to the effect of the great resultant moreover it was in the reverse direction, for the temporary variation was from east to west, whilst the mean variation was from west to east

2946 *Another mode of showing how much* the action of nearer portions of the atmosphere may overpower and hide the effect of the whole mass, is to draw the line of mean variation for the twenty four hours through such a photographic record as that just referred to, and then it will be seen in every part of the course how small the mean effect on the needle is, compared to the irregular or comparatively local effect for the same moment of time The magnet with which these observations were made, is a bar of steel 2 feet long, 1½ inch broad and a quarter of an inch thi[illegible]
obed [illegible]
a sh [illegible] numerous
cases [illegible] irregular variation would be several hundred of times greater than the mean. Still all these irregularities and overpowering influences of near masses are eliminated by taking the mean of several years' observation and thus a true result is obtained, to which the hypothesis advanced may be applied and so tested

2947 Returning for a short time to the annual variation (2882), I may observe that it has been a good deal considered in discussing the daily variation The arrangement of the magnetic effects by Colonel Sabine at Hobarton, *Toronto*, *St Helena and elsewhere* into monthly portions, proves exceedingly instructive and important, especially for places between and near the tropics It supplies that kind of analysis of the annual variation which is given by the hours for the daily variation Every month, by a comparison of its curve with those of other months, tells its own story, at the same time that it links its predecessor and successor together

2948 I shall have occasion to trace these monthly means hereafter; but in the meantime refer to the effect of the sun's annual approach and recession indicated by these means, as according with the hypothesis in respect to near and distant actions (2945) Hobarton and Toronto are in opposite hemispheres, so that the sun whilst approaching one recedes from the other, and the amount of variations therefore changes in opposite directions Below is the average for each month, derived in the case of Hobarton from a mean of seven years, and in that of Toronto from a mean of two years

	Hobarton Lat 42° 52 5 S	Toronto Lat 43° 39 35 N
January	11 66	6 51
February	11 80	6 40
March	9 50	8 50
April	7 26	9 52
May	4 56	10 34
June	3 70 Winter	11 93
July	4 61	12 70 Summer
August	5 89	12 68
September	8 24	9 72
October	11 01	7 59
November	12 05 Summer	5 75
December	11 81	4 47 Winter

The two stations are in latitudes differing only 47′ from each other and the extreme difference of the atmospheric effect between summer and winter differs as little being at Hobarton, which has the highest latitude, 8′ 35, and at Toronto 8 23

2949 *According to Dove, the northern hemisphere* is warmer in July than the southern hemisphere by 17° 4 Fahr, and colder in winter by only 10° 7 the numbers being as follows

July	Northern hemisphere	71° 0	62° 3 the whole globe
	Southern hemisphere	53° 6	
January	Northern hemisphere	48° 8	54° 15 the whole globe
	Southern hemisphere	59° 5	

The mean for the whole year is 59° 9 for the northern hemisphere, and 56° 5 for the southern Therefore, as Dove further shows, the *whole earth is in July*, when the *sun is shining* over the terraqueous parts, 8° higher in temperature than in January, when it is over the watery regions and from the influence of the same cause, the mean of the southern hemisphere is 3° 4 below the mean of the northern half of the globe The difference between Jan-

uary and July is for the northern hemisphere 22°2, and for the southern only 5°9 These differences are so peculiar in their arrangement and so large in amount, that they must have an effect upon the distribution of the magnetic forces of the earth, but the data are not yet sufficient to enable one to trace the results Sabine indicates a probability from his analysis of observations that the sum of the earth's magnetic force is increased in intensity when the sun is in the southern signs, i e. in our winter (2891) I should have expected from theory that such results would have been the case, at least in those parts where the dip was not very great, because a colder atmosphere ought to conduct the lines of magnetic force better, and therefore the systems round the earth ought at such a time to condense, as it were, in the cooler parts It would be doubtful, however, whether the needle would show this difference, because the lines of power would not be restrained above, as in the case formerly supposed (2922), but could gather in from space freely From what has been said, however, it will be evident that such a conclusion can only be drawn with any degree of confidence from observations made pretty equally over both hemispheres

origin of the lines should prove to be more or less deeply situated

notice briefly such points as have occurred to my mind

2952 The *varying pressure* of the atmosphere, over a given part of the earth's surface, ought

the oxygen in a given space is paramagnetic in proportion to its quantity (2780), and therefore it does not seem possible that that quan-

tenth of the whole sum without producing a corresponding alteration in the distribution of the magnetic force, the lines being drawn together and the force made more intense by an increase of the quantity or of the barometric pressure, and the reverse effects produced at the occurrence of diminished pressure.

2953 At any spot which is towards the con-

whilst from the other it is retreating Whether these changes (which I think must occur) produce by vicinity effects large enough to become sensible in our magnetic instruments is a question to be resolved hereafter To sug-

stream like the trade-wind, may have a constant effect, but if, when the arrangement of the lines of magnetic force through the atmosphere is in a given state consequent upon the condition of the atmosphere at that time, a wind arises which mixes regions of cold and warm air together, or makes the air more dense

their difference from neighbouring regions of clear air, and at other times by absorbing the sun's rays, and causing the evolution of sensible heat at different altitudes in the atmosphere at different places, or preventing its evolution more or less at the surface of the earth. Those masses of warmer or colder air of which meteorologists speak, which being transparent are not sensible to the eye, will produce their proportionate effect. And hypothetically speaking, it is not absolutely impossible that the hot and partially deoxygenated air of a large town like London, may affect instruments in its vicinity, and if so, it will affect them differently at different times, according to the direction of the wind.

2956. If one imagines on the surface of the earth a spot which shall represent the resultant there of the atmospheric actions above, and can conceive its course as it wanders to and fro, under the influence of the various causes of action which have been in part referred to, whilst it still travels onwards with the sun, one may have an idea of the manner in which it may affect the various observatories scattered over the earth. I believe that its course, as regards the east and west direction of its wanderings, is partly told in the photographic registerings of Greenwich and Toronto, being there mingled in effect with other causes of variation. This spot may be concentrated or diffuse, may pass away and reappear elsewhere, there may even be two or more at once sufficiently strong to cause vibrations of the needle between them.

2957. The *aurora borealis or australis can* hardly be independent of the magnetic constitution of the atmosphere, occurring as it does within its regions, and perhaps in the space above. The place of the aurora is generally in those latitudes the air of which has a distinct magnetic relation, by difference of temperature and quantity, to that at the equator, and the magnetic character both of the aurora and of the medium in which it occurs ties them together, therefore, to be aware of and to understand in some degree the latter, will probably direct us to a better comprehension of the former. The aurora is already connected with magnetic disturbances and storms, it may in time connect them with changes in the atmosphere in a manner not at present anticipated, and as the suggestion is founded upon principle it seems deserving of consideration.

2958. Can the magnetic storms of Humboldt be due to atmospheric changes? *This is a question* on which I would offer the following observations. Supposing a magnetic rest in the atmosphere, and that all local or irregular variations remained unchanged for the time, then if a change happened in one place it would be felt instantly everywhere else over the whole earth, and in proportion to the distance from the place of change. It would be felt instantly, because the impulse would not be conveyed chiefly or importantly *through the matter of* the earth or air, but through the space above, for the lines there are affected by changes in that part of them which passes through the atmosphere, and, as I conceive would affect the other lines in space round our globe, which would in turn affect those parts of their lines, which, passing downwards to the earth, govern the needles below. In space, I conceive that the magnetic lines of force, not being dependent on or associated with matter (2787, 2917), would have their changes transmitted with the velocity of light, or even with that higher velocity or instantaneity which we suppose to *belong to* the lines of gravitating force, and if so, then a magnetic disturbance at one place would be felt instantaneously over the whole globe.

2959. But the difficulty is to conceive an atmospheric change sufficiently extensive and sudden to make itself perceived everywhere at the same time amongst the comparatively local variations that are continually occurring. Still, if there were a lull in these disturbances by the opposition of contrary actions or otherwise for the same moment of time at two or more places, those places might show a simultaneous effect *of disturbance, and that* even when the cause might be very little or not at all sensible in the place where it occurred. A simultaneous change over an area of 600 or 800 miles in diameter, might produce less alteration in the middle of that area than at the extremities of radii of 1000 miles.

2960. It becomes a fair question of *principle* to inquire how far masses of the air may be *moved* by the power of the magnetic force which pervades them. When two bulbs of oxygen in different states of density are subjected to a powerful magnet with an intense field of force the mechanical displacement of one by the other is most striking. Whether in nature the enormous volumes of air concerned, and the difference in intensity of the earth's magnetic force at the different latitudes where these may be supposed to be located, combined with the difference of temperature, are sufficient to compensate for the small portions of oxygen in the

air and the smaller variations in density, is a matter that cannot at present be determined The differential result of motion, as has been shown is very great where the direct result as

mous masses is concerned

2961 Now in the matter of difference of intensity, Gay Lussac and Biot conclude from

there was a little diminution, and Professor Forbes from his experiments made in different parts of Europe [2] concludes that there is a decrease of the force upwards Such decrease may be a real consequence due to the difference of distance from the source of the terrestrial mag

Lussac's account of the air brought from above, it was as 0 5 to 1 0, compared with the density below

ponent, in the latitude where Gay Lussac and Biot made their aerial voyages It is also just possible that the observers may have been in such relation to the heated or cooled air about them as to have had the difference observed produced, or rather affected, by some of the circumstances just described (2951)

2962 Whether the result obtained by Gay-Lussac and Biot indicate a change of power due to distance or not this we know, that there

a cubic inch of oxygen can exert a force equal to the tenth of a grain, subject to the action of our powerful magnet, we may well conceive that the enormous sum of oxygen present in

only a few miles of heated or cooled atmosphere, can compensate for the great difference of magnetic force, and so by a change of place cause currents or winds having their origin in magnetic power In such a case we should have a relation of magnets to storms and the magnetic force of the earth would have to do with the mechanical adjustments and variations of the atmosphere sometimes causing currents

of observations and the data derived from

the atmosphere as a mere mixture of oxygen and nitrogen is shown to possess them also (2862) [3] It varies in its magnetic powers by causes which act upon it under natural circumstances, and make it able to produce some such effects as those I have endeavoured generally to describe

[1] *Annales de Chimie* Ann XIII Vol LII p 86.
[2] *Edin. Phil Trans* 1836 Vol XIV, p 25
[3] *Philosophical Magazine* 1847 Vol XXXI pp. 406 409

respect to the action and the phenomena it can [illegible]

[illegible]

and it presents itself at a time when we have no clear knowledge of any other physical cause for the variations, but are constrained vaguely to refer them to imaginary currents of electricity in the air or space above, or in the earth beneath

2965 The causes, both of the original power and of its secular variations, are unknown to us But if, accepting the earth as a magnet, we should be able to distinguish largely between internal and external action, and so separate a great class of phenomena from the rest, we should be enabled to define more exactly that which we require to know in both directions, should be competent to state distinctly the problems which need solution, and be far better able to appreciate any new hints from nature respecting the *source* of the power and the effects that it presents to us

2966 The magnetic constitution of oxygen seems to me wonderful It is in the air what iron is in the earth The almost entire disappearance of this property also, when it enters into combination, is most impressive, as in the oxynitrogens and oxycarbons, and even with iron, which it reduces into a condition far be- [illegible]

[illegible]

exists between them in relation to static elec-tricity (1464) and the lightning flash Chlorine bromine, cyanogen and its congeners, chem [illegible]

[illegible]

hope to effect by a torsion balance, in course of construction (2783) Indeed, I hope that this great subject may be largely touched and tried by experiment as well as by observation and therefore gladly make it part of these experimental researches

2968 One can scarcely think upon the subject of atmospheric magnetism without having another great question suggested to the mind (2442) What is the final purpose in nature of [illegible]

[illegible]

there is one or more, for nothing is superfluous there We find no remainders or surplusage of action in physical forces The smallest provision is as essential as the greatest None is deficient, none can be spared

Royal Institution, September 14, 1850

APPENDIX

RECEIVED NOVEMBER 12, 1850

[illegible]

been published The data for Hobarton and Greenwich are in the volumes of observations for those stations

TORONTO Longitude 77° 5′ W Latitude 43° 40′ N Approximate declination 1° 25′ W Mean inclination 75° 15′ N.

Diurnal variation of the Declination in the several months, from July 1842 to June 1848 inclusive

Increasing numbers denote a movement of the south or upper end of the magnet towards the West

Toronto mean time	0h Noon	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h Midn	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
Jan	0.87	0.00	0.00	0.53	1.44	2.28	2.89	3.47	4.43	4.53	4.39	4.08	3.66	3.42	3.63	3.87	4.46	3.84	3.88	4.44	5.48	5.80	4.79	3.03	3.30
Feb	0.78	0.00	0.06	0.94	1.58	1.91	2.73	3.13	4.02	4.44	4.69	4.45	4.31	3.81	3.54	4.07	3.97	4.86	4.95	5.20	5.97	5.70	4.64	2.53	3.43
Mar	1.44	0.01	0.00	0.59	1.74	2.90	3.82	4.77	5.63	6.60	6.47	6.86	6.04	6.42	6.55	6.34	6.69	6.59	7.10	8.30	9.38	9.40	7.15	4.22	5.21
Apr	1.25	0.00	0.16	1.02	2.76	4.12	5.14	6.31	7.05	7.14	7.60	7.66	7.39	7.32	7.65	7.82	8.08	8.33	9.46	10.09	10.20	9.10	6.87	3.74	6.09
May	1.16	0.00	0.29	1.56	3.24	5.11	6.08	6.27	6.18	6.75	7.36	7.49	7.40	7.26	6.72	7.10	7.80	9.70	11.02	12.16	12.03	10.28	6.00	3.52	6.39
June	1.37	0.00	0.02	0.94	2.53	4.35	5.45	6.11	6.10	6.66	6.66	6.87	6.77	6.50	6.37	6.36	7.29	9.03	11.34	12.34	12.09	10.54	7.67	4.04	6.12
July	1.53	0.09	0.00	0.84	2.18	3.98	5.20	5.77	6.31	6.34	7.31	7.38	7.67	7.06	6.42	6.37	6.88	8.53	10.54	12.01	12.22	10.69	7.65	4.27	6.13
Aug.	1.11	0.00	0.73	2.61	4.52	6.12	7.60	7.52	8.05	8.97	8.51	8.40	8.14	7.69	7.65	7.83	8.24	9.50	12.09	13.89	13.79	11.51	7.31	3.73	7.31
Sept.	0.03	0.00	0.76	2.92	4.62	6.04	6.78	6.83	7.62	7.84	7.83	7.08	7.50	7.66	7.53	7.77	8.45	8.38	9.79	11.16	10.24	8.60	5.34	2.25	6.37
Oct.	0.48	0.00	0.31	1.38	2.38	3.06	3.84	4.33	4.92	5.76	5.68	5.48	5.00	5.21	4.89	5.16	5.82	5.74	5.50	6.39	7.32	7.02	5.17	2.63	3.89
Nov	0.75	0.00	0.34	1.37	2.21	2.91	3.96	4.89	5.16	5.70	5.54	5.26	4.51	3.79	3.80	4.51	4.44	4.99	4.95	5.70	6.31	6.08	4.57	2.35	3.92
Dec	1.20	0.18	0.00	0.61	1.67	2.56	3.30	3.89	4.39	4.62	4.95	4.48	4.09	3.49	3.04	3.56	3.92	4.02	3.81	4.18	4.50	5.22	4.67	2.83	3.30

Mean Diurnal variation of the Inclination in the several months, from July 1842 to June 1848

Increasing numbers denote increasing inclination

	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
Jan.	1.02	0.77	0.53	0.22	0.00	0.09	0.16	0.21	0.25	0.33	0.34	0.38	0.47	0.54	0.58	0.45	0.33	0.28	0.22	0.21	0.36	0.54	1.04	1.06	0.43
Feb	0.86	0.61	0.36	0.12	0.01	0.00	0.09	0.12	0.19	0.26	0.27	0.31	0.37	0.45	0.49	0.44	0.41	0.30	0.27	0.44	0.69	0.70	0.79	0.86	0.39
Mar	1.02	0.77	0.47	0.14	0.00	0.00	0.12	0.22	0.24	0.35	0.40	0.44	0.45	0.53	0.50	0.50	0.46	0.46	0.47	0.62	0.81	0.95	1.00	1.05	0.50
Apr	0.90	0.77	0.54	0.17	0.05	0.00	0.14	0.35	0.49	0.53	0.49	0.61	0.56	0.59	0.64	0.61	0.60	0.66	0.74	0.80	0.90	1.03	1.16	1.16	0.61
May	0.83	0.52	0.22	0.06	0.00	0.11	0.27	0.33	0.47	0.62	0.64	0.66	0.76	0.86	0.87	0.89	0.92	1.04	1.00	1.01	1.11	1.29	1.30	1.12	0.70
June	0.89	0.60	0.26	0.05	0.00	0.00	0.16	0.34	0.53	0.68	0.73	0.83	0.84	0.90	0.91	0.98	1.03	1.05	1.08	1.12	1.17	1.27	1.37	1.19	0.75
July	0.87	0.55	0.17	0.07	0.00	0.06	0.17	0.24	0.39	0.40	0.51	0.56	0.62	0.56	0.66	0.78	0.83	0.97	0.81	0.80	0.88	1.03	1.14	0.93	0.57
Aug	0.85	0.51	0.21	0.00	0.02	0.04	0.25	0.40	0.42	0.44	0.48	0.55	0.53	0.64	0.65	0.73	0.74	0.84	0.89	1.00	1.09	1.25	1.26	1.13	0.62
Sept	1.35	0.82	0.35	0.10	0.00	0.10	0.29	0.40	0.53	0.55	0.57	0.63	0.68	0.70	0.70	0.75	0.57	0.65	0.68	0.95	1.28	1.64	1.85	1.71	0.75
Oct	0.93	0.67	0.39	0.14	0.00	0.06	0.21	0.30	0.37	0.39	0.40	0.49	0.62	0.45	0.40	0.33	0.22	0.22	0.32	0.55	0.85	1.04	1.15	1.11	0.48
Nov	0.94	0.76	0.45	0.22	0.11	0.18	0.12	0.18	0.20	[illegible]	0.23	0.33	0.33	0.31	0.21	[illegible]	0.12	0.07	0.00	0.08	0.42	0.14	0.89	1.00	0.32
Dec.	0.91	0.89	0.51	[illegible]	0.05	0.01	0.02	0.16	0.21	0.27	0.33	0.30	0.38	0.34	0.28	0.22	0.14	0.09	0.09	0.00	0.17	0.34	0.66	0.81	0.31
[Ho]urly means	0.94	0.69	0.37	0.13	0.02	0.03	0.17	0.28	0.36	0.42	0.45	0.51	0.55	0.57	0.57	0.58	0.53	0.54	0.55	0.63	0.81	0.93	1.13	1.10	0.54

Toronto Mean Diurnal variation of the Total Force in the several months, from July 1842 to June 1848.
Increasing numbers denote increasing Force Mean Total Force at *Toronto* 13.9
The figures express the changes in parts of the whole Force.

Toronto mean time	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
Jan	005	011	017	023	022	024	023	023	023	020	019	015	010	009	004	003	004	005	008	009	010	003	000	000	012
Feb	006	012	019	022	024	026	026	027	025	023	019	017	009	005	003	004	003	006	009	010	016	004	000	001	013
Mar	004	011	019	026	029	031	031	031	028	025	020	014	005	002	002	002	003	003	010	013	013	007	002	000	014
Apr	012	020	031	039	045	045	044	039	034	027	020	012	008	007	003	000	009	011	013	012	012	009	006	006	019
May	004	013	015	031	038	042	038	035	029	025	017	011	004	002	002	003	008	010	015	013	009	003	000	000	015
June	003	008	017	025	029	031	030	028	022	018	014	011	006	002	002	001	006	011	014	014	010	005	002	000	013
July	015	019	030	038	044	047	043	039	031	026	021	015	007	004	000	002	005	011	016	017	015	014	010	002	020
Aug	027	034	044	042	057	057	051	046	041	032	023	010	006	001	003	000	006	018	026	026	024	019	019	021	026
Sept	029	043	053	060	060	056	052	050	044	038	034	029	019	007	000	001	004	009	018	022	028	015	016	021	030
Oct	013	021	027	032	032	033	033	034	031	026	023	018	007	003	005	002	000	005	011	014	018	011	008	006	017
Nov	007	014	022	026	028	025	025	028	024	018	015	011	007	004	001	003	000	003	007	009	008	002	001	003	011
Dec	004	010	019	020	023	021	021	021	019	018	017	012	010	008	006	007	003	003	007	006	006	006	001	000	011
Means	011	018	026	032	036	037	035	033	029	025	020	015	008	005	003	002	004	008	013	014	014	008	005	006	017

Mean Temperature of the Air in the several months, from July 1842 to June 1848, in degrees of Fahrenheit's scale.

	0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Jan	27.8	28.3	28.6	28.5	28.0	27.1	26.3	25.9	25.5	25.3	26.3	24.8	25.8	23.5	23.4	21.6	23.2	23.0	23.7	23.6	23.9	24.8	26.0	27.1	25.45
Feb	27.4	28.2	28.5	28.5	28.0	26.9	25.6	24.6	23.8	23.2	22.7	22.2	22.0	21.7	21.3	20.9	20.5	20.2	20.0	19.9	20.9	22.9	24.9	26.3	23.80
Mar	33.8	34.4	35.0	34.9	34.3	33.6	31.9	30.5	29.5	28.6	28.0	27.3	27.3	26.8	26.3	26.2	25.8	25.5	25.0	25.9	27.8	29.9	31.6	32.8	29.71
Apr	47.6	48.5	49.0	49.0	48.6	47.9	46.1	43.5	41.8	40.7	39.8	39.3	39.1	38.9	37.9	37.3	37.0	36.6	36.8	39.2	41.5	43.6	45.2	46.6	42.55
May	59.0	59.9	60.2	60.3	60.3	58.9	58.1	55.2	52.6	50.7	49.7	48.8	48.0	46.9	46.3	45.8	45.1	45.2	47.5	50.6	53.0	55.2	56.8	58.0	53.04
June	66.7	67.5	67.9	68.3	68.5	68.1	66.6	63.9	60.6	58.4	57.0	56.1	55.7	54.8	54.1	53.3	52.7	52.9	55.6	58.5	60.8	62.7	64.4	65.6	60.86
July	72.9	73.7	74.5	74.8	74.7	74.3	72.7	69.2	65.1	62.9	61.8	60.7	59.8	58.9	58.3	57.6	56.9	58.9	59.8	63.4	66.0	68.2	70.1	71.5	66.02
Aug.	73.0	73.9	74.5	74.8	74.6	74.1	72.5	68.4	65.3	63.6	62.4	61.6	60.7	60.0	59.4	58.7	58.3	58.1	59.6	63.2	66.3	68.7	70.6	72.1	66.43
Sept.	63.9	64.5	64.9	64.9	64.7	63.7	61.1	58.3	57.1	56.0	54.9	54.2	53.8	53.3	52.7	52.2	51.6	51.1	51.7	54.2	57.0	59.5	61.5	62.9	57.90
Oct.	49.7	50.3	50.5	50.3	49.6	47.8	45.8	44.7	43.9	43.1	42.3	41.6	41.0	40.4	40.1	39.9	39.5	39.4	39.6	40.4	42.8	45.6	47.5	48.9	44.35
Nov	39.5	40.0	40.1	39.9	39.0	37.7	36.9	38.3	35.9	35.7	35.3	34.9	34.3	34.0	33.7	33.4	33.2	33.3	33.6	33.6	34.6	36.2	37.7	39.9	36.15
Dec.	29.9	30.4	30.7	30.5	29.8	28.9	28.2	27.9	27.5	27.3	27.0	26.9	26.6	26.0	25.7	25.5	25.5	23.5	25.1	25.0	25.4	26.6	27.9	29.1	27.44
Means	49.27	49.97	50.37	50.39	50.01	49.17	47.65	45.69	44.05	42.96	42.27	41.52	41.16	40.41	39.93	39.35	39.11	38.97	39.84	41.46	43.33	45.32	47.02	48.31	44.43

St Petersburgh Longitude 38° 18′ East Latitude 59° 57′ North Mean declination 6° 10′ West.
Mean Diurnal variation of the Declination in the several months, from 1841 to 1845 inclusive
Increasing numbers denote a movement of the south or upper end of the magnet towards the West.

Mean time	Noon 0h 21¼m	1h 21¼m	2h 21¼m	3h 21¼m	4h 21¼m	5h 21¼m	6h 21¼m	7h 21¼m	8h 21¼m	9h 21¼m	10h 21¼m	11h 21¼m
	′	′	′	′	′	′	′	′			′	
Jan	0.27	0.00	0.36	1.24	1.69	1.99	2.39	3.28	4.03	4.85	4.58	4.65
Feb	0.84	0.00	0.09	0.57	1.55	2.84	3.54	3.83	4.03	5.18	5.67	5.49
Mar	0.89	0.00	0.04	1.16	2.88	4.16	5.36	6.29	6.73	6.78	7.40	7.84
Apr	1.59	0.00	0.36	2.17	4.03	5.54	7.04	7.93	8.33	8.02	9.30	9.17
May	1.02	0.00	0.62	2.13	3.68	5.49	6.96	7.44	7.18	8.82	7.44	8.24
June	1.77	0.00	0.00	1.37	2.92	4.52	5.76	6.25	6.25	6.56	7.13	7.13
July	1.46	0.04	0.00	1.11	2.39	3.94	4.96	5.27	5.98	5.98	6.78	7.49
Aug.	0.27	0.00	0.40	2.44	4.16	5.94	7.04	6.73	7.49	7.27	7.35	7.27
Sept	0.57	0.00	0.84	2.57	4.30	6.33	6.79	7.49	7.97	8.06	8.33	7.49
Oct.	0.31	0.00	0.48	1.77	3.59	4.03	4.87	5.76	6.02	6.56	6.91	6.20
Nov	0.09	0.00	0.36	1.55	1.00	2.71	2.79	3.15	3.81	4.39	4.47	4.34
Dec	0.53	0.00	0.36	1.24	1.82	2.39	2.79	2.97	4.03	4.56	4.56	4.52
Means	0.80	0.00	0.33	1.61	2.90	4.16	5.02	5.62	5.99	6.24	6.66	6.65

Mean time	Midn 12h 21¼m	13h 21¼m	14h 21¼m	15h 21¼m	16h 21¼m	17h 21¼m	18h 21¼m	19h 21¼m	20h 21¼m	21h 21¼m	22h 21¼m	23h 21¼m	Means
	′	′	′		′	′	′	′	′	′	′	′	
Jan	4.43	3.72	3.77	3.10	2.57	2.22	2.35	2.17	2.08	1.86	1.42	1.02	2.49
Feb	5.27	4.52	4.34	4.65	4.34	3.00	4.03	3.77	3.50	3.23	2.61	1.46	3.29
Mar	6.69	6.51	5.76	6.11	6.38	6.16	6.65	6.56	6.73	6.38	4.96	2.79	5.05
Apr	8.68	8.46	8.73	8.59	9.17	9.30	9.48	10.01	10.68	9.75	7.58	4.61	7.01
May	9.55	8.73	8.82	9.66	10.23	10.72	11.12	11.39	11.12	9.92	7.49	3.54	7.01
June	7.49	8.28	8.68	9.70	10.23	10.94	11.30	11.39	11.52	10.10	7.35	4.12	6.70
July	7.68	7.71	8.42	8.55	9.30	9.52	9.83	9.75	9.04	8.46	6.96	3.90	6.02
Aug.	8.02	8.11	8.06	8.55	9.30	9.88	10.19	10.19	9.44	8.42	5.67	3.16	6.47
Sept	7.04	7.31	7.40	6.78	7.04	6.91	7.27	7.31	7.13	6.25	4.12	1.95	5.72
Oct.	5.71	5.18	4.78	4.39	4.16	3.99	4.21	4.83	5.09	4.65	3.32	1.59	4.10
Nov	3.68	3.06	2.75	2.35	2.22	1.82	1.82	1.00	1.77	1.77	0.93	0.57	2.26
Dec	3.68	3.10	2.88	2.53	2.04	1.82	1.77	1.77	1.82	1.68	1.28	0.93	2.29
Means	6.41	6.22	6.20	6.25	6.42	6.43	6.67	6.75	6.66	6.04	4.47	2.47	4.87

Mean Temperature of the Air in the several months, from 1841 to 1845 *inclusive Fahrenheit's scale*

	°	°	°	°	°	°	°	°	°	°	°	°
Jan	20.28	20.71	20.67	20.41	19.82	19.89	19.73	19.71	19.74	19.76	19.67	19.49
Feb.	18.34	18.58	18.70	18.65	18.27	17.35	16.88	16.52	16.32	16.09	15.95	15.67
Mar	25.61	26.30	26.97	27.01	27.01	26.13	24.74	23.58	23.20	22.44	21.94	21.31
Apr	37.85	38.07	38.58	38.81	39.53	38.63	36.64	[illegible]	33.35	32.38	31.42	30.72
May	53.46	53.80	54.31	54.72	55.10	54.29	52.23	49.84	47.91	46.19	45.38	43.90
ne	63.03	63.48	63.83	64.36	64.97	64.07	61.90	59.97	58.19	56.48	55.04	54.07
ly	66.44	66.93	67.21	67.46	67.93	[illegible]	65.28	63.61	62.01	60.57	59.56	58.86
ig.	67.10	68.00	68.56	68.69	69.23	68.50	65.73	63.70	62.26	60.89	60.05	59.22
pt	54.60	55.66	55.91	55.78	55.83	54.56	52.62	51.16	50.15	49.43	48.89	48.31
t	41.02	44.80	42.76	41.98	41.78	40.92	40.30	39.89	39.56	39.31	38.56	38.52
ov	20.73	30.22	[illegible]	29.75	[illegible]	28.06	[illegible]	28.67	28.58	28.41	28.52	28.49
ec.	26.04	26.45	26.40	26.27	26.13	25,91	25.70	26.02	25.62	25.48	25.48	25.32

	°	°	°	°	°	°	°	°	°	°	°	°
Jan	19.38	19.33	19.29	19.19	19.04	18.90	18.79	18.79	18.74	18.81	19.24	19.98
Feb.	15.55	15.48	15.39	15.19	14.97	14.88	14.76	14.65	15.10	15.66	16.61	17.35
Mar	20.70	20.07	19.82	19.26	18.84	18.54	18.34	18.74	19.87	21.38	22.95	24.53
Apr	30.07	29.55	29.08	28.61	28.36	28.42	20.21	30.63	32.16	33.75	35.39	36.79
May	43.16	42.37	41.83	41.47	41.56	42.73	44.19	46.06	47.88	49.57	51.17	52.65
ne	53.26	52.58	52.00	51.50	52.27	53.33	54.95	56.57	58.21	59.72	59.02	62.15
ly	58.05	57.33	56.86	56.48	56.68	57.53	58.86	60.59	62.06	63.43	64.76	65.90
ig.	58.14	57.60	57.20	56.57	56.14	56.73	57.65	59.45	61.29	63.12	64.71	66.06
pt	47.75	47.25	46.85	46.44	46.26	46.06	46.17	47.21	48.76	50.56	52.20	53.37
t	38.32	38.14	38.00	37.85	37.73	37.67	37.53	37.71	38.28	39.11	40.12	41.04
ov	28.47	28.45	28.42	28.27	28.13	28.04	28.00	27.95	28.07	28.42	28.83	29.37
ec.	25.21	25.12	24.96	24.85	24.85	24.92	25.03	25.03	25.14	25.25	25.39	25.79

Washington, U S —Longitude 77° 2 West Latitude 38° 54 North Mean declination 1° 25 West Mean dip 71° 20′ North

Mean Diurnal variation of the Declination in minutes and temperature in Fahrenheit's scale, of the months of the years 1840, 1841, 1842, which are specified

Increasing numbers denote a movement of the south or upper end towards the East

Mean time	Noon h m 0 12	h m 2 12	h m 4 12	h m 6 12	h m 8 12	h m 10 12	h m 12 12	h m 14 12	h m 16 12	h m 18 12	h m 20 12	h m 22 12	Mean
				′							′		′
Jan 1841-42	4.10	5.20	3.98	2.52	0.87	0.69	1.01	1.62	1.68	1.71	0.91	0.29	2.04
Feb 1841-42	3.55	5.28	4.22	2.83	1.60	0.94	0.84	1.25	0.81	0.82	0.60	0.35	1.76
Mar 1841-42	6.34	7.51	6.28	4.25	2.68	2.31	2.50	3.00	1.71	1.13	0.00	1.70	3.30
Apr 1841-42	6.56	8.33	6.4[illegible]	4.41	3.22	1.97	2.24	1.35	0.73	0.46	0.00	2.19	3.15
May 1841-42	7.72	8.57	6.36	4.45	3.82	3.47	3.25	3.05	2.63	0.73	0.00	4.25	3.09
June 1841-42	8.55	9.47	8.00	5.33	4.91	4.04	4.05	4.32	3.44	0.63	0.00	4.53	4.73
July 1840-41	8.42	9.87	8.07	5.75	4.57	3.52	3.60	1.40	2.93	0.98	0.00	3.82	4.36
Aug 1840-41	10.94	10.81	7.95	6.00	4.07	3.55	4.48	4.64	4.04	1.35	0.00	5.69	5.30
Sept. 1840-41	8.76	8.44	5.43	4.45	2.62	3.31	2.83	2.88	2.44	0.87	0.00	4.22	3.83
Oct 1840-41	5.65	5.87	4.35	2.47	1.41	0.58	1.41	1.89	1.51	1.35	0.00	1.75	2.34
Nov 1840-41	4.63	4.70	3.33	1.60	0.51	0.74	1.14	1.41	0.82	0.71	0.00	1.83	1.79
Dec 1840-41	3.93	4.90	3.30	1.02	0.10	0.36	0.62	1.53	0.93	2.00	1.02	0.87	1.79

Temperature

Mean time	Noon h m 0 12	h m 2 12	h m 4 12	h m 6 12	h m 8 12	h m 10 12	h m 12 12	h m 14 12	h m 16 12	h m 18 12	h m 20 12	h m 22 12
	°	°	°		°	°	°		°	°	°	°
Jan 1841-42	38.28	40.83	40.18	36.68	33.47	34.24	32.37	32.10	31.71	30.33	31.63	36.76
Feb 1841-42	40.03	42.51	42.28	43.22	35.38	33.56	32.58	31.22	30.81	30.18	31.44	30.72
Mar 1841-42	51.30	53.61	53.28	49.16	46.20	44.37	42.49	41.26	40.06	39.87	42.29	45.09
Apr 1841-42	57.68	59.81	60.20	57.22	52.18	49.12	47.91	46.91	46.12	45.49	49.33	54.02
May 1841-42	66.27	68.43	65.69	65.09	59.81	58.70	55.19	53.34	52.42	55.50	59.72	63.23
June 1841-42	70.32	81.85	82.75	76.50	72.21	68.70	66.81	66.04	65.07	69.28	73.69	77.37
July 1841	81.13	81.53	84.60	81.33	74.93	71.58	69.78	69.09	66.78	70.64	75.19	78.79
Aug 1840-41	78.70	80.73	80.09	75.93	71.48	68.00	66.82	65.12	64.17	65.60	65.73	76.09
Sept 1841	71.66	76.50	76.30	72.30	68.51	64.07	62.70	61.90	61.00	61.29	65.73	71.02
Oct 1841	55.30	57.00	56.20	52.94	49.40	46.60	44.90	43.70	42.30	41.70	45.00	51.61
Nov 1841	48.00	49.20	48.50	47.30	44.20	43.20	41.60	40.70	39.40	38.90	39.20	44.10
Dec 1841	39.20	41.30	40.60	37.95	36.26	34.70	33.60	33.10	32.90	31.60	31.69	38.00

LAKE ATHABASCA Longitude 111° 18′ West Latitude 58° 41′ North Mean declination 28° East

Diurnal variation of the Declination in the months of October, November and December 1843, and Jan and Feb 1844

Increasing readings denote a movement of the south or upper end of the magnet towards the West

Mean time	h m 12 55	h m 13 55	h m 14 55	h m 15 55	h m 16 55	h m 17 55	h m 18 55	h m 19 55	h m 20 55	h m 21 55	h m 22 55	5 minutes to noon h m 23 55	h m 0 55	h m 1 55	h m 2 55	h m 3 55	h m 4 55	h m 5 55	h m 6 55	h m 7 55	h m 8 55	h m 9 55	h m 10 55	5 minutes to midnight h m 11 55	Mean time
Oct 1843	1 13	7 49	6 23	18 05	21 32	8 55	13 35	9 90	10 7[illegible]	7 03	2 29	2 70	0 00	0 29	0 0	0 08	0 4[illegible]	2 88	1 88	3 75	3 47	3 30	8 4[illegible]	0 49	13 days obs in Oct 1843
Nov 1843	3 73	5 17	6 74	9 07	10 35	10 80	9 40	8 80	7 63	6 54	1 10	0 00	1 06	1 57	1 93	2 73	2 94	3 34	4 52	4 97	5 43	7 08	3 04	3 63	25 days obs in Nov 1843
Dec 1843	3 04	6 16	5 57	5 65	9 23	7 61	9 78	6 73	6 58	5 33	1 94	0 55	0 03	0 00	0 83	[illegible] 37	2 63	3 81	4.18	3 57	4 35	7 19	4 05	6 05	25 days obs in Dec 1843
Jan 1844	5 69	8.49	6 97	12 57	16 29	10 05	9 97	10 02	9 96	7 95	4 99	2 10	0 39	0 00	2 75	1 67	2 47	3 63	4 7[illegible]	5 15	5 44	3 97	6 71	2 18	25 days obs in Jan 1844.
Feb 1844	4.27	4 93	8 46	10 55	14 80	14 87	14 06	12 10	12 76	8 64	2 82	2 93	1 55	0 00	1 48	3 24	3 76	4 52	4 96	5 48	5 58	4 09	6 98	5 40	25 days obs in Feb 1844.

FORT SIMPSON Longitude 121° 30 West Latitude 61° 52′ North

Diurnal variation of the Declination in the months of April and May 1844

Increasing numbers denote a movement of the south or upper end of the magnet towards the West

Mean time	15 minutes past midnight h m 12 15	h m 13 15	h m 14 15	h m 15 15	h m 16 15	h m 17 15	h m 18 15	h m 19 15	h m 20 15	h m 21 15	h m 22 15	h m 3 15	15 minutes past noon h m 0 15	h m 1 15	h m 2 15	h m 3 15	h m 4 15	h m 5 15	h m 6 15	h m 7 15	h m 8 15	h m 9 15	h m 10 15	h m 11 15	Mean time
Apr 1844	5 82	6 03	17 46	25 16	22 90	36 80	[illegible]6 20	37 60	30 14	25 27	18 77	8 [illegible]7	5 72	[illegible] 16	0 00	1 37	1 23	0 43	0 [illegible]0	4 04	4 62	1 26	2 86	5 55	20 days obs in Apr 1844
May 1844	1 56	7 77	11 71	15 63	17 19	23 7[illegible]	28 22	3[illegible] 69	[illegible]9 80	[illegible]0 [illegible]9	15 51	0 49	4 74	3 75	0 70	0 75	0 80	0 00	0 10	1 90	6 72	3 51	2 29	1 67	18 days obs in May 1844

TWENTY-SEVENTH SERIES[1]

§ 33 *On Atmospheric Magnetism (continued)*

Received November 10, Read November 28, 1850

¶ ii *Experimental Inquiry into the Laws of Atmospheric Magnetic Action and their Application to Particular Cases*

2969 Believing that experiment may do much for the development of the general principles of atmospheric magnetism, and produce rapidly a body of facts on which philosophers may proceed hereafter to raise a superstructure, I endeavoured to find some means of representing practically the action of the atmosphere, when heated by the sun, upon the terrestrial

various cases supplied by the magnetic observatories scattered over the earth At first I endeavoured for the sake of convenience, to attain this desired end by means of a horseshoe

restrial force near the magnet and the great prominence of the poles of the latter gave rise to many inconveniences, which soon caused me to reject that method and have recourse to a ring helix and voltaic apparatus Considering the new use to which this helix is to be applied, the interest of the results and the instruction that may be drawn from them I shall be excused for being somewhat elementary in the description of its character and action

2970 The helix consisted of about 12 feet of covered copper wire formed into a ring having about twenty five convolutions, and being 1½ inch in external diameter The continuations of the wire were twisted together so as to neutralize any magnetic effect which they could produce and were long enough to reach to a voltaic arrangement and yet allow free motion of the helix The requisite amount of magnetic power in the helix may be judged of by the following considerations suppose a declination needle freely suspended, and then the helix placed at a distance in the prolongation of the needle with its axis in a line with the latter, and with that side towards the needle which will at small distances cause repulsion The needle will point in the magnetic meridian, with a certain amount of force but as the helix

rium, but beyond which it has a position of stable equilibrium, the distance varying with the strength of the exciting electric current The power of the helix should be such that when end on to the needle the latter has a position of stable equilibrium in the meridian One pair of plates is quite sufficient to make the helix as magnetic as is needful for distances varying from 4 to 24 inches When a needle is properly arranged with either a magnet or a helix to the north or south of it as above described, if the magnet or helix be moved west the near end of the needle will move east, and contrariwise

2971 As is well known such a helix has a system of magnetic lines which, passing through its axis then opens out and turning round on the outside re-enters again at the axis, the circles of magnetic force being everywhere perpendicular to the electric current traversing the convolutions of the helix and now I had at a moment s notice, a source of lines of magnetic power exactly of the kind required to produce, in association with those of the earth, a disposition of the forces coinciding either with those of paramagnetic or diamagnetic polarization (2865, 2877)

2972 For let *Fig 17* represent a section parallel to the axis of the ring helix, then the two circles may represent the disposition of the

[1] *Philosophical Transactions* 1851 p 85



Fig 17

tion of the earth's power Choosing the two positions in which the axis of the helix is parallel to the natural direction of the power, as shown by a free needle, at the place of observation, then two contrary effects are produced, which, as regards the lines exterior to the helix system, correspond to the polarity of paramagnetic and diamagnetic conductors If, for instance, the helix is so placed that the polarity of its magnetic lines, exterior to and in the plane of the ring, accords with that of the earth's force, as in *Fig 18*, then the earth's lines are de-

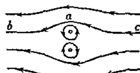


Fig 18

flected as represented, and a magnetic needle placed at *a*, which had taken up its position

standing as a tangent to the curvature and therefore will be deflected sometimes one way and sometimes another, as it is carried along the line (or through the neighbouring lines), in place of remaining parallel to itself, as it would

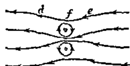


Fig 19

Needles placed at *d* and *e* would again be de-

position of the forces, as the former did the diamagnetic condition

2974 It is not pretended that the whole of these arrangements of forces is like those of the cases of paramagnetic and diamagnetic conductors Independent systems are here introduced into the midst of the earth's magnet-

great field of nature, are comparable in their direction, and may be considered as representing each other

2975 In order to obtain a simple result of

at the foot of it parallel to the magnetic equator at London Then suspending a small mag-

its position changed, and the disposition of the forces of the earth under the influence of the helix was as in *Fig 18*, or like that of a diamag-

tact with the battery, the motion and direction of the needle is then easily observed or if it

raises the effect to any degree required

2977 There are certain positions in respect to the needle as a centre which must be clearly comprehended The magnetic axis is a line through the centre of the free regular needle parallel to the direction of the earth s lines of force whatever that may be at the place where the experiments may be made The magnetic equator plane is a plane passing through the centre of the needle perpendicular to the mag

declination needle points This position always

its mechanical axis the latter being in the magnetic axis

2978 When the ring helix situated as before explained (2975) was anywhere in the plane of the *magnetic merid an* it exerted no action on the declination needle tending to change its position When the helix was anywhere in the

helix does not affect the position of the needle

2979 These two planes of no variation divide the space around the magnet into four

neutral line into one or the other quadrant the declination of the needle changes

2980 If the helix be above or below the mag

mences with the helix above the equator and in the plane of the magnetic meridian north of the needle if it then proceeds by west to south and on by east to its original position the north end of the needle will first go westward will then stop and return eastward passing the mean position and will finally return westward and

long as it is in the west the deflection will be more or less but not change in direction as regards the neutral place The position of the helix north or south of the needle is of no consequence as to the direction of the declination

again it does not change whilst the helix remains east or west of the needle and its plane of mean declination

2981 If we carry the helix round the needle in a plane perpendicular to the planes of the magnetic equator and meridian so as to traverse in succession the four quadrants then the needle makes *two* to and fro vibrations (instead of one) during the circuit Thus beginning with the helix in the neutral position over the needle and going round by west and below and then upwards on the east side to its first posit on the north end of the needle will first pass westward then eastward then westward after that eastward and finally westward to its original or neutral position

2982 As the helix is carried from the neutral planes (2978) into any of the quadrants the power of affecting the declination of the needle is first developed and then increases every way from the edges of the quadrant until it attains its maximum force at the middle Hence the maximum deflection east or west is when the helix is in the middle of each quadrant Therefore when the helix is carried from the middle of one quadrant to the middle of the next only *one motion* in the needle appears as for instance an increasing westerly declination though the direction of the declination in relation to the mean position has been reversed in that time and there was a moment when the needle had no extra declination but was *in* that mean position So also as the helix moves over one quadrant from one neutral plane to another though the declination of the needle produced by it has not changed in direct on

hence it is that though there are *four* departures of the needle from and return to the neutral or mean position whilst the helix circumscribes *it in an east and west vertical plane*

(2981), there are only *two* complete journeys of the needle

2983 The amount of the deflection diminishes as the distance of the helix from the needle increases, and the contrary

2984 Two other needles were slung (2975) very oblique to the magnetic axis one with its north end upwards and the other with its north end downwards, and these were submitted to the action of the helix as the former had been (2978) They were affected exactly in the same manner showing no difference, i e, a given end always moved the same way for the same change in position of the helix If the helix was very near, then one pole was a little more influenced than the other in certain positions but its removal farther off took away that difference (which is easily accounted for [2970]) and produced pure results The place of the helix above or below the prolongation of the line of the needle made *no difference*, provided it was in the same place as regarded the magnetic equator of the earth s lines of force passing through the needle

2985 For the [illegible]

in the plane passing through the magnetic meridian of London

2986 The [illegible]

these two planes divided the sphere of action into fo[illegible]

is in the upper north segment or the lower south segment, the upper or south end of the needle is deflected towards the south if the helix be in the upper south or lower north segments, the upper or south end of the needle is deflected towards the north If the helix be carried round the needl[illegible]

direction as before in the case of the declination magnet (2982)

2988 In other words when the helix was anywhere below the magnetic equator, the *lower* or north end of the needle tended to point outwards from it or outside of it being as it were *repelled* by the axis of the helix but *drawn* by the outer curved lines of force *Fig 20* (2992) Or if the helix were above the equator then the *upper* or south end of the needle went outwards from the helix moving exactly in the same direction in relation to the helix as the lower pole did before

2989 The support of the needle was turned round 90°, which therefore removed the plane in which the needle could move 90° from the magnetic meridian This carried the plane of no action on the needle 90° round so that it now coincided with the magnetic meridian and the plane which standing east and west was before neutral was no longer a plane of indifference but in fact passed at the middle of the segments through the places of strongest action

2990 Here with *inclination* as before with *declination* it is not the direction in which the needle stands that determines what action the [illegible]

case are much better compared and remembered when the simple law of change in the whole line of force is ready in the mind for reference The equatorial plane and the magnetic axis are now the only parts in which the helix can be without affecting the position of the needle the first gives places (for the helix) with a stable position for the needle, and the second such as have either stable or unstable positions according to the helix distance

2992 If the helix be out of the plane and axis then the end of the needle nearest to it leans from it as if repelled If the helix be carried round in a circle of latitude the end of the needle moves round before it just like the upper end of the needles at Hobarton and Toronto

represent the result A result exceedingly simple and in perfect accordance with the diamagnetic disposition of the forces produced by the helix (2972) as the two dotted lines indicate

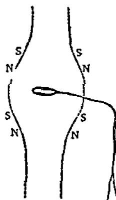


Fig 20

2993 As an expression of the facts for use in applying them to the explanation and illustration of natural phenomena it may be said in respect to *declination*

dip it will send the south or upper end west or if on the east of a needle having south dip (being of course then itself inverted [2972]) it will

being above the needle tends to send the upper end of the needle or line of force from it If the

In fact every case is included in this result that if the helix be diamagnetically adjusted (2975) for a free needle whether it is above or below the needle or on this side or that the

only say that the effects

due to the cooling of the atmosphere (3003 3010)

2995 In these experiments that the laws of deflection might appear in their simplicity the needle was suspended in the air and the representation of the sun s action carried round it in all directions But in nature the air is only above the needle and the earth as a magnet is beneath it In the natural case also there is the fixation of the lines in the earth (2910) which tends by holding them below the surface to give them an amount of deflection *at* the surface far beyond what they would have if they were as free to move in the earth beneath as in the space above [1] and though this deflection would coincide with that produced by the helix alone still it was important to verify its effect I therefore took a bar magnet 30 inches long and weak in condition and suspended the needle above it in various parts as so to have the effect of north or south dip to any degree or no dip at all near the middle parts The effect of absence of air from beneath was also in a cer

The results with the helix were now influenced greatly in the *amount* of the deflection but not in the direction When the helix affected the direction of the needle it was according to the above laws

2996 In the consideration of natural phenomena the magnetic axis and also the planes of the magnetic equator and meridian being circles or planes of no deflection are very important Changing as they do with every change either of place or declination or dip they require some ready means of illustration and can hardly be comprehended in their effects

then in another colour drawn for each place its

the hours before and after noon of any given

[1] Referring to the typical globe of cold air (2874)

place, I have the means of ascertaining with sufficient accuracy when the sun is in any par

supply I have found the globe very useful and I

and t e astronomical meridian of the place of observation towards the zenith The observer can then regard it as from the place of the rising sun

2997 Though we thus have the experimental conditions of a needle under an action like that resulting in nature from the presence of the sun (2920) I do not pretend that they can be applied without modification to natural phenomena but only that they give very important aid in the study of the latter and the rationale of their action The atmosphere instead of being illimitable wraps the earth round as a garment the influence as it extends from the region of a t

calculations founded upon careful observations can determine accurately In regard to the development of the air action it would I think be very interesting to ascertain even roughly, the daily variations of m t the bottom

ternal power (or the absence of such changes) when freed from those dependent upon the atmosphere.

2998 Another reason why the experimental results must not be applied too closely is as follows If

regular order Still the irregularities must extend their influence very far upwards so that the contortions of the magnetic meridians or lines of force are not likely to be effaced or much diminished at the region coinciding with the place of the atmosphere s effect

2999 But though the lines are irregular in the large space affected by the sun the result will be expansion of the whole as a system and diamagnetic polarity The lines of force below will be affected by those above and so though a perfect similarity between different places is not to be expected still the kind of change at

quadrants for any given month of the year or hour of the day

3000 The passage of the magnetic meridian

side where it was obtuse was also confirmed

net

3001 The passage of the magnetic equator by the sun is also important since the direction of the diurnal variation of the experimental

ward towards the astronomical meridian either on the east side or the west and comes into effect during the more influential *hours of the* sun or the cold In all those

the [illegible] at different places, th[illegible]g of the neutral planes by the sun and acting region must take place under an extreme variety of conditions the unravelling of which I think will be much assisted by knowledge such as that which the preceding experiments and principles give The sun may be astronomically either north or south of the needle, and yet the declination of the needle not change in direction (2980) or if there were much mean declination as at Greenwich, then it might be astronomically east or west of it, and yet the declination produced not change its direction The sun region may be south of a place and yet send its upper end farther south (2990) for all will depend upon its position in relation to the magnetic meridian and the magnetic axis, which are in most cases very far removed from those that are astronomical added to all these causes of variety, there is the fixation of the lines of force in the earth (2919), which tends to give a further diversity to them

3002 In the former paper I considered only the effect of air raised in temperature above the mean condition (2895), illustrating it by the sun's effect in the middle of the day, *now* I purpose considering that which will be produced by the cold of night, which reduces the air of a given region below the mean air temperature of that place. When a portion of air is so cooled, its conduction power is increased in conjunction with the warmer air of surrounding regions it deflects the lines of magnetic force passing through both, as indicated by the type globe (2864, 2874), and acquires what I have called *conduction polarity* (paramagnetic), meaning thereby simply that the lines of force draw together in the middle of the cooled air

3003 Theoretically, the effect of a cold region of air coming up from the east would be to make the magnetic lines of force, as they leave the earth, advance or bend towards it, because those in and about the cold air are inflected in to it, and as those immediately west of the cold region move into or towards it, so those farther west, being in part relieved from their tension, will also move east, and thus an effect, the reverse of that of the sun (2877, 2972), or the same as that of the helix in the paramagnetic position (2973, 2994), will be produced The upper ends of needles at places having dip show this deflection of the upper part of the lines of force, because they move by, with, and in them

3004 So as cold approaches, the lines will *lean towards it until it is in the position of maximum action in the eastern quadrant, then they will return (in declination) before the cold, until* both it and the line (or needle) are in the magnetic meridian, after which, as the cold travels on westward the needle will follow it west until the cold has attained its place of maximum action in the west quadrant (2982), and then, as the cold retreats the needle will return east to its mean place, assuming that there is no other action for the time than that of the cold region The upper end of the free needle, therefore, at any given place will tend *towards* the cold region, just as before it tended *from* a warm region, and as the declination is affected, so also the inclination will be If the cold be on the magnetic meridian of a place within the tropics, as St Helena or Singapore, it will increase the dip there, whilst at the same moment it is diminishing the dip at places south or north of it having considerable dip, a result which follows directly from the inflection of the lines of force into or towards the cold region

3005 The chief regions of heat and cold on the same parallel of latitude do not follow each other at equal intervals of time It is difficult to make a judgement regarding their interval in the atmosphere above but the maximum of cold on the earth for the twenty-four hours, is assumed by many as being seventeen hours after the preceding noon and only seven hours from the coming noon This brings into consideration the joint effect of hot and cold regions in deflecting the lines of force, especially during the forenoon and middle of the day If a cold region be only three and a half hours west of a place at the same time that the warm region is three and a half hours east of it it is very manifest that the joint effect of the two for both act then to cause the same deflection, will be far greater than that of the heat or cold alone, or than any corresponding effect at other periods, for neither twelve hours after, nor at any other time will there be an equivalent condition of circumstances, and so it is also for other combinations of hot and cold regions the effect of which will vary both by position and by their extent A free needle is held in tension by the lines, which are themselves governed by the hot and cold regions of atmosphere, it probably never occupies its mean place, but is always in the resultant of these ever-present and ever-varying causes of change

3006 As the earth revolves under the sun each place would have speaking generally a maximum and a minimum of temperature for its atmosphere in the twenty four hours But looking at the globe as a whole there would be

polar regions which as regards the twenty four hours would not be at the pole but in some place of high latitude and perhaps as before seven or eight hours before noon These cold regions will be very seriously affected in their extent and place and power by the position of the sun between the tropics for as he advances to one tropic the cold region there will diminish in extent and force whilst the other will grow up in importance and whilst they thus vary in their power of influencing the gene

are made manifest to us as I believe in the night and morn

to some new ones between the tropics for the purpose of explaining if I can the principles of night action of retardation more or less of the effects in relation to local time of the difference in direction of the declination variation in different months for the same place at the same h

to d action for the time I will endeavour to use the word *region* for that purpose meaning thereby not the whole extent of heated or warmed air nor the centre but the chief place of the altered portion It is very manifest that in some days in March or September *all* the air that is east of the meridian at 21ʰ or 22ʰ may be considered warm in comparison to that which is then west of the same meridian and that a resultant of action which shall be the same for all places cannot exist

3008 We are to remember that the *eastening* and the *westening* of the upper end of the needle of which I always speak is produc

two ways The needle travels as positively by the withdrawal of a direct cause of action as it

duced the great east swing

3009 *St Petersburgh* has a mean declination of 6° 10 W and a dip of 70° 30 N therefore

whereas in winter it is farther off and also in

Pl XV

3010 In December or January being St

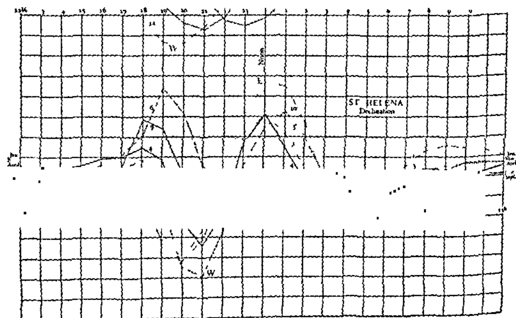
or 17ʰ then again stops or nearly so until 21ʰ

PLATE XV(c)

CAPE OF GOOD HOPE
Declination

Noon

SINGAPORE
Declination



still the explanation, according to my view, is as follows St Petersburgh is a place in which, from its position, the upper cold, consequent upon the daily withdrawal of the sun, would produce a paramagnetic action (2994, 3003) This action, as the sun set, would begin to appear on the east, and I conclude that at 9^h–11^h the cold region ...

... is able at 9–11 o clock, during which the needle is stationary, to counteract any remaining tendency westward, and after that to draw the line of force and the needle end eastward until 17 o'clock, and to hold it there, after which the sun sends it eastward in the ...

I think, to be a very natural consequence of the probable ...

which he begins to exert a westening action on the ...

(2982), and also so far off that it has no power to ...

this the ...

3011 The ...

I may also point out here, for use in the summer months, that the maximum heat varies three hours in the *opposite direction* so that whilst from the highest to the lowest temperature in the day is only eleven hours in summer, it is nineteen hours in winter, as may be seen by the temperature table, p 725 As the day comes on, therefore in January the highest temperature is only five hours after the lowest, which accords generally with the assumed cause of the effects on the needle [1]

3012 As I am endeavouring to make St Petersburgh a general case of night action for the explanation of corresponding effects at other places, so I may notice that the night action must contain a portion of sun effect which combines with that of the cold The action of the sun is known by observation to be very extended, in the case of St Petersburgh, the sun, when at the southern tropic and on the meridian is between 80° and 90° from the station, and yet we see by the observations and curves ...

placed by air, and in the representative experiments with a helix (2995) does so send it eastward when a magnet is interposed The night action ought therefore to be greatest in winter, ...

ronto and elsewhere, may depend upon the manner in which, at different hours, these two causes (probably with others) combine together

3013 Though the declination varies little or nothing between 17^h and 21^h ...

... time of greatest ... tion and by their ... change into increasing ...

3014 In the month of February the same remarks apply but as the sun is now coming from the southern signs and drawing nearer to

than half a minute (of a degree), and by absolutely overcoming it and making a return west-

cold ceases sooner and sooner being in January and April 17^h and 13^h respectively The minimum of temperature also retreats being for the same month 20^h and 16^h On the con

ty four hours make one revolution in the same

west to east

his paper upon the St Helena phenomena [1]

3039 3065)

3017 The paramagnetic character of the east-

deed it is not fair to endeavour to explain the results of the assigned cause by taking only one element of three into consideration What we require ultimately to know is all the changes of a free needle in position and in respect to power All are important and all should be considered at once I presume that the theory of the variations cannot advance very far without their joint consideration

3018 *Greenwich* presents a fine case of the night episode and the different directions of the magnetic variation for the same hours in different months In these respects it is very much like St Petersburgh but has great additional interest because of the large western declination [2] and the effect produced by it on the places of the active quadrants (2979 3000) and the times of the variation phenomena On setting up its position on the globe (2996) it will be seen that the equatorial plane is not likely to be much concerned in the midday action and that the sun or warm region passes nearly across the middle of the two chief quadrants in summer which with its nearness at the

[1] *Philosophical Transactions* 1847 p 51
[2] Mean declination 2?°51 W Mean inclination 69°N

same time ought to make the midday swing to east very great In winter it is farther off and in much weaker parts of the quadrant, so that the swing ought to be far less and such is the case. The greatest summer variation is 11′ 30, and the least winter variation only 5′ 88 In April, May, June, July and August, the great west declination of the south or upper end of the needle is at 19ʰ 20′, and the chief east position at 1ʰ 20 The latter position remains the same all the year round, but the extreme westering is in the other seven (cold) months at 9ʰ

action grows up, until very prominent, in the winter months, through the strengthening of the cold action (3006), when the sun is towards the southern tropic and in the weaker parts of the segments The assumed principles of this

warm region passes it, especially in winter, for then the sun crosses it about 10 o'clock, and in summer about 11 o'clock Hence the swing ought to be earlier in winter than in summer, though, because of the slower angular motion of the warm region in relation to Greenwich

to accord remarkably with the fact The swing begins at 17ʰ in the winter but not until 19ʰ in the summer, and ending at the same hour at both

noon in winter than in summer, hence the swing is thrown forward in time in winter, and though prolonged, its termination coincides

3020 As the region precedes the sun, the degree of mean declination here ought to make

the time (3032)

3021 We are to remember also that in winter the sun or warm region passes the magnetic

mer, and perhaps even before it ceases to come nearer, and so the eastern after-effect on it ought to be greater, which it is This eastern effect should be strengthened also, because the [illegible] of the warm region on the needle ought

fore 19ʰ (3016) is very marked at Greenwich,

six hours the needle passes to extreme east, performing, according to the observations a fourth of the whole swing in the first two hours, a half in the next two, and a fourth in the remaining two, the journey being no doubt with

first rapidly increasing and then rapidly diminishing velocity In this transit of the region, the sun is for about two thirds of the time in the eastern quadrant, and one-third in the western, and his path in the latter third forms almost the base of an equilateral triangle with Greenwich, having the magnetic meridian for one side, so that all that time it is close to and *therefore has strong action on the needle (3000)* *The sun is at* 1^h *in such a position as respects* this angle that if we assume the region to be somewhat in advance of it the latter would be in that place where it could exert its maximum eastening effect, and therefore after that, as it recedes westwards, would let the needle return from east to west, as it does, following it The needle continues to go west, passing its *mean* place for the month about 7^h in the meantime, before that, at a little *after* 6 o'clock, the sun has left the *western segment* by passing the magnetic equator, it has not yet set to Greenwich, and if it have any action, it will, because of the segment it is now in (2979), still be to carry the needle end *westward* The end in fact continues to go westward slo [illegible] o'clock [illegible] as the [illegible] as it o[illegible] the gre[illegible] The whole progres[illegible] is very simple, and apparently a natural result of the assumed cause Effects of cooling no doubt come in, but the cold region has diminished in intensity and extent (3006), has retreated *northward, and its action appears in combining with the former to produce only variations in the velocity of the change*

3023 *Then for the* winter, let us consider January, and, as the eastening is a minimum in all the months at 1 o clock, after the sun's passage across the meridian, let us begin the cycle there At 1^h the upper end of the needle is at extreme east, and the amount of the variation not half what it was in summer, the sun being now far off The sun and warm region pass the magnetic meridian about 21^h or 22^h, and therefore, in the hours before and after that, should produce the full west to east effect At 1 o'clock the needle returns west, following the retreating sun, and does so quickly *for seven or eight hours, or up to* 9^h [illegible] which time the warm [illegible] [illegible] the needle end west of [illegible] mean position Then an action of the following kind supervenes; the needle remains stationary until 11^h, after which it goes east at midnight and until 15^h, again remains stationary, or nearly so, for two hours, then eastens again, slowly at first and afterwards more rapidly, until 1^h, when it has attained its maximum eastening and the place from whence it set out

3024 This *night action* is another case of the *action of a cold region like that considered in respect to St Petersburgh (3010)* It appears to me that at 11^h the immediate sun action and return west after it, were over, that the cold region which was coming round from the east did then act by its paramagnetic condition (combined with the complementary effects of the sun's action on the other side of the globe), and set the needle eastward, as it would be competent to do (2994, 3010) until 14^h or 15^h In eastening, the *needle does not arrive* at the *mean place, but is still* 1′ *west of it*, and the reason why it hangs there from 15^h to 17^h and then begins to go east again, more and more *under* the sun's action, is probably that, as *the sun* rises in the southern tropics, his distance and position bring the resulting distant warm region gradually into action with that of the nearer cold that at first he stops the action of the latter, and then as he advances combines with and finally replaces it, causing the usual swing to come on, slowly at first and then quickly, from west to east by 1^h How this would happen is well seen, *both as respects* the place of *the sun in the southern hemisphere*, and in the *two magnetic segments*, by *reference* to the *globe (2996) and the diagram of the curves of variation Pl XV*

3025 Considering another and an intermediate month as March, at 1^h the upper end of the needle is at extreme east then until 9^h *it follows* the sun as before (3023) From 9^h to 11^h *it* is stationary then the paramagnetic action of cold from the east occurs, and the needle moves east until 13^h It is then stopped, and two hours sooner than before, for the sun now appears to Greenwich as early as 6 o clock, and in a more favourable position for effect, both as regards the magnetic meridian and the segment in which it has for the time its place, and so the needle is actually sent west for a couple of hours It is then held almost *steady* until 19^h, after which the *great sun-swing occurs* The *holding* west and *yet the absence of more westening between* 15^h *and* 19^h, *is not inconsistent with the southern place of the warm region, and it is probable that* at that *time the dip is increasing, an effect* which would accord very *harmoniously*

with the condition of matters at the time

3026 Other months are on this or that side of March in respect to their effects, the corresponding month on the opposite side of the year (September) is the same as March, except in that portion of effect which is consequent upon a month following one that is warmer or colder

may be considered together A very important comparison of the phenomena at both places has been already made by Colonel Sabine in relation to the variations of declination inclination, and total force [1] When examined by the globe (2996) the distribution of the quadrants is nearly alike, the sun being in two chief east and west quadrants from about 18 to 6 o clock, or during the day The sun is in more

and 5.2 in winter The night action at both is alike in character, and has been sufficiently explained

the total force at Hobarton and Toronto may be compared with and applied to the hypothesis but I hesitate to enter upon them in this general view, inasmuch as these and the declination variations should be closely considered and compared together at every hour for each particular place The inclination variation at Hobarton is greatest in its summer, being then 2 18, and least in winter, or 1' 28 as was

o clock for September, at 1 o'clock for June

has made thereon

[1] In reference to the position in advance of the

3032 I am inclined to refer much of this precession of the warm region at Toronto to the geographical distribution of land and water there The Atlantic is on the east and the continent of America on the west of the station, and as Dove's charts and results intimate, the temperature may rise higher and sooner over the land than over the water, and so throw the warm region in respect of Toronto in advance of the time or of the sun In the case of Hobarton the arrangement is different, and, in fact, what land there is is between the advancing sun and the station and would tend to hold the warm air region back, and tend to cause its time to coincide with that of the sun Even the greater difference in summer than in winter at Toronto appears to be explicable in the same manner, by reference to the relative position of the sun at the two seasons to the land and water arrangement

3033 Though the temperature on the earth's surface is a very uncertain indication of that above (2937) yet as far as it goes it harmonizes with this view The maximum temperature occurs sooner after midday at Hobarton than at Toronto in the former place it is at 2 o'clock and very regular and the minimum at 16–19 o'clock, being earlier in summer and later in winter At Toronto the maxima are from 2 to 4 o clock, and the minima at 16–18 o clock The maxima are later in summer than in winter the minima are as at Hobarton, being later in winter than in summer The mean temperature is low-

[illegible]

3034 It is probable that effects of retardation and acceleration, in respect of the passage of the local part of the warm region for a given place may occur in many parts of the globe, and these will require to be ascertained for every locality and for the different seasons there A place having the reverse position of Toronto would have a reversed or retarded effect and

[illegible]

that time make its diurnal revolution but vary in the velocity of its different parts at different periods of its journey and that in a different degree and order for different latitudes, and

[illegible]

probably be altered, one place holding the influence longer and another dismissing it sooner, analogous to two conditions of stable and unstable equilibrium

3035 *Cape of Good Hope*[1] This station is in longitude 18° 33′ east and latitude 33° 56 south The mean declination is 29° west and the dip 53° 15′ south The amount of dip, combined with the position of the place, gives a magnetic equator, which passes nearly through the astronomical poles and so the sun's path in every part of the year intersects it almost at right angles and at the same hour, namely, about 20 past 7 o clock in the morning and evening or at 19^h 20′ and 7^h 20′ But because of the great declination the sun is in the astronomical meridian two hours before he arrives at the magnetic meridian in Cape winter, and half an hour or more before in Cape summer

3036 The sun passes obliquely through both the chief quadrants and across their central parts pretty equably but because of the western character of the mean declination he is much nearer the Cape when in the eastern than when in the western quadrant for all the months and so the coming up effect, i e , the westening before the mid-day swing commences, ought to be more powerful than the easteming after it is over and such is the case This is in beautiful and striking contrast to Greenwich which, having the same kind of mean declination and nearly in the same degree, is on the north of the sun's path and therefore the luminary passes its magnetic meridian before 12 o'clock, and for a time still approaches the station the result is the reverse effect to what we have at the

[illegible]

that the day-swing is very feeble as it ought to be the sun being in the northern tropic and

[illegible]

After that th[illegible] slowly until

[1] See tables pp 752 753 and curves of variation Pl XV

til 19h, when it has attained its maximum east position This effect I believe to be due to the cold which in these hours is approaching from the east, and setting by its paramagnetic action (3002) ...

... about 23h, at which time the sun swing from west to east comes on being over by 2h or 3h, completing the daily variation, after which the needle goes west, following the sun as before In this sun-swing is seen the effect of an inclined magnetic meridian (3000), for though ...

... the swing occupies about four hours, the warm region is probably near the magnetic meridian about half past 12 or 1 o clock

3038 *January* presents a case of Cape summer The day-swing is then from 21h to 1h or 2h After 2h the needle upper end follows the sun westward until 6h, and then moves a little eastward for two hours after this it moves slowly westward again the whole effect being as if a cold region had occurred on the east had passed ov...

... to extreme east in the sun-swing through an amount of variation more than twice as great as that produced in July or Cape winter

3039 I think the above is a true explanation of the reverse motion of the needle in the months of ...

... passes forward, both it and the sun region conspire at 19h to carry the needle westward, for though they have opposite actions they are then also on opposite sides of the magnetic meridian (3005) In the summer the cold region has much less power, occurs earlier,[1] soon passes over, for the summer sun is behind it, and then rather aids the sun in carrying the needle westward

3040 Some of the other months are still more ...

... ate months are easily traced, and found to be ...

... others (3053) The curves of December and January are more equal ...

... later, being from 21 to ...

... reality, because it ties the considerations of time more simply together

3042 The inclination at the Cape varies ...

... warm region are greatly to the north of the Cape it appears that the dip is increased

[1] The minimum temperature below is three hours earlier

February, March and April the dip diminishes at that time, and the resulting rotation of the pole is of the contrary kind, or like that at St Helena (3057) and Singapore (3061, 3067)

3043 The daily variations of intensity at the Cape are remarkable In the months October to April it is at a chief maximum at 19ʰ or 20ʰ, by noon it is reduced to a minimum as the sun

mum about 18ʰ or 19ʰ next morning In the months from May to September the chief maximum is at 21ʰ or 22ʰ, which is followed by a minimum at 1ʰ or 2ʰ, due to the day effect Then comes on the 5ʰ maximum, and after thirteen hours or more the second minimum as low almost as the former and only three hours before the chief maximum so that this maximum is placed between minima close on each side of it

3044 These are exactly the months during which the upper end of the needle moves eastward in early morning up to 19ʰ, and that is just the hour when the minimum intensity occurs From 18ʰ or 19ʰ to 21ʰ the intensity rises to a maximum precisely as the lines of force are moving westward before the sun region, prior to their quick return east and as they return in their quick journey so the intensity falls to a minimum again, and is at that minimum at 1ʰ or 2ʰ just as the swing is over Here is a very close connection, and it is curious to see the needle end at east with minimum power at 18ʰ and again also at 1ʰ, remembering that in that time it has swung from east to west and back to east again

3045 *St Helena*[1] This is a station which Colonel Sabine has distinguished as of the high-

tion to the striking fact that the course of the needle is in some months in one direction, and in other months in the contrary for the same hours of the day[3] De la Rive attempted to explain this fact,[4] but Sabine has stated that this explanation is not satisfactory[5]

[1] See tables pp 754 755 and curves of variation Pl XV

3046 St Helena being a small island in the south Atlantic ocean is removed about 1200 miles from the nearest land The longitude is 5° 40′ west, the latitude 15° 56′ south, the mean declination 23° 30 west, and the mean dip 22° south Hence there are three quadrants concerned in the day action of the sun, especially when that luminary is south of the equator The sun is south of St Helena itself in the months of November, December, January and February, or for nearly that time, it is north of the island for the rest of the year At one time the sun passes the astronomical meridian before it arrives at the magnetic meridian, and at another time the contrary is the case In addition to these peculiar circumstances St Helena is a place of great local differences, and also its dip is so low that the sun's day effect is almost constantly to depress and lessen it

3047 In June and July the sun rises to St Helena in the south east quadrant, about an hour after, it passes into the north-east quadrant, and crosses it towards the southern end being then at mid-distance in the quadrant about one-third of the length, or nearly 60°

tremity In our winter, December and January the sun also rises to St Helena in the south east quadrant as before, but it now remains in it until 22ʰ, being for much of the time in strong places of action it enters the north east quadrant to the south of St Helena, and does not remain in it two hours, being then only in the weakest part of it, it leaves it again *before* arriving at the astronomical meridian, then enters the north west quadrant gliding along near to its southern side and is within two thirds of an hour of leaving it when it sets to St Helena

3048 As June presents the aspect of circumstances approaching nearest to that of a station farther south, as Hobarton or the Cape so I will consider the variations for it first The

ready said The eastening from midnight and before I refer to the paramagnetic action of the cold which *comes* up from the east as before (3003 3025 3037) the rapid increase of the *eastening from* 16^h to 19^h is consistent with the increasing cold of the early morning and also *with the* circumstance that the sun and its representative region are then passing from the south-east into the north east quadrant and must be not far from the neutral line for that is the time of quickest transit of the needle As the sun advances into the north-east quadrant it first stops the eastening as at 19^h and then converts it into westening (3014) wh h m

with the magnetic meridian and after this hour it is determined east a little until 3^h This effect from 22^h to 3^h I consider as the sun swing to the east and I think, examining the globe (2996) its small amount in declination is quite consistent with the relative positions of St Helena and the warm region combined with those of the active and neutral parts of the quadrants traversed during the time From 3^h to 5^h the needle end moves westward following the sun and that effect harmonizes with th

ing on.

3049 Colonel Sabine has shown that the months of M

tran

ward in conformity with all former observations and then comes on the sun swing from west to east between 22^h and 24^h and a hold at extreme east an hour longer The shortness in time of this transit is I think a beautiful point The sun is still north of St Helena but is now so much nearer that he passes through the *same angle* east and west in respect to the place of observation in less than half the time of the former sun effect in June (3041) After this the needle end travels west from 1^h to 6^h following the sun as on other occasions and then from 6^h to 9^h it moves a little east by the

16^h and 18^h of the coming day

gion are so far advanced in their respective quadrants that they combine to carry the needle end west as before until 20^h and then comes on the swing from west to east until 24^h

at equidistant points from and passes over the magnetic meridian sooner and also from the effect of an accumulative action added to it

13h when the latter is in its mean position The cold region then appears to draw it westward until 16h when its distance increasing it releases the needle and lets it return east until 18 o clock when the latter is still west of its normal position and then the sun region rising up helped perhaps by the cold that immediately precedes it which is probably now over or beyond the magnetic meridian sets it toward the west prior to the sun swing

3052 In December and January the sun is south of the station This makes no difference

tive effects of the preceding months (3050 3053) added to its own effect at the time still it is in weaker parts of the quadrant and whilst in the chief segment is almost up in the corner and near the place where the two neutral planes

though in the latter month it crosses the magnetic meridian after and in the present before midday still there is only half an hour s difference from one to the other and the observations are perhaps not close enough to allow one to separate its peculiar effect out of an interval of four hours Besides accumulative causes may interfere The places of the December curve are altogether a little more west than those for October

3053 The *cumulative* effect of preceding months is very important and well shown at St Helena (3050) Thus, taking the Septem

est month for the second comparison Up to 20h its curve changes like the October curve but the upper end of the needle is all the time about half a minute east of its place in October At 20h the needle in October begins to swing from west and reaches extreme east at 24h in March it westens until 21h, then returns and reaches extreme east at 1h so that the swing is an hour later, and during that time the end

is from half a minute (of space) to a minute more west than in October This difference I believe to be due to the cumulative effect of the months between October and March during which time the heat has been diminishing in the northern hemisphere and increasing in the south Similar results in other months make it probable that the effect of the atmosphere though induced by the sun lags behind the luminary considered as in his astronomical position all the year round and that therefore in advancing to and receding from a tropic he seems to do less in the first instance and more in the second than is due to his place for the time

3054 But where circumstances are apparently equal a difference also arises Thus from March to April in one direction and from September to October in the other might be ex

bine s curves *between* September and October and near together whilst the other two are far apart This effect I refer to the different conditions of the two hemispheres as regards heat (Dove) From September to October the sun is passing from a hemisphere having a mean temperature in summer 17° 4 above that of the other hemisphere for its winter but in March and April it is departing from a hemisphere having a mean summer temperature of only

3055 I need not go further into the declination variation of St Helena the lines for the other months are subject to the observations already made Colonel Sabine s important query of the cause of difference in direction for different months (3045) appears to me at present to

tion very simple in character being a maximum at 7h and a minimum at 22h and 23h with only

which time therefore the dip is decreasing then it returns east until it reaches the neutral position the dip decreasing the while still more

The needle still continues to go east to com

ing dip at 5^h or 6^h the westening has almost ceased and an hour after the dip is at its maximum

sents the motion of the upper end of the needle at St Helena as the sun comes up from the east is above westward and downward and back below to east then rising to be repeated in the next twenty-four hours This is the reverse direction to the representative ellipse for

fore deflects the lines of force upwards and increases the d

Singapore [1] This is a very interesting stat on

ing in our summer the sun passes through the east and west northern quadrants during the daytime in our winter through the east

will suffice for the present occasion (3048) The sun-swing occurs at the same period and the

tor and therefore under the sun in Sep the eastening is less the westening is less and

[1] See tables pp 756 75 and the curves of variation Pl XV The data for Singapore are deduced from the recent very valuable labours of Captain Elliot

gether during the day in the southern quadrants (3058) As the sun comes on from 16^h or 17^h, the upper part of the line of force moves westward (the lower being fixed in the earth) until 19 or 20 o clock The sun is at this time in the south-east quadrant and it might be expected perhaps that the motion of the north or upper end of the needle shoul l be to tl e east if there were any cl ange at all But there are two or three reasons from the hypothesis why this should not be For that effect tl ere should first of all be no dip and in the next place if there were no dip the sun is so nearly in the neutral line of the magnetic equator that the deflection if any would have been very small On the other hand the lines of force have dip to

iation of declination can now only send the northern parts as they rise out of the earth and

they show that the northern hemisphere as a whole is warmer tl an the southern (2949) Again if we look at the meridian of Singapore we shall find that there is far more continent on the north of it to pro luce a higl er temper

ing to make us suppose that the warm region of the atmosphere is relatively north of the sun s place and perhaps even of Singapore (3067)

morning sun action takes it up and drives it more quickly west until about 20^h when the sun swing east occurs The curve in these months is very simple in its character the night or cold effect appears to be but small being indicated rather by a hesitation than by a distinct movement east

3065 The easterly movement of the needle end in May June July and August and the westerly movement in November December

with it but still keeping north of it Hence the two cold regions which come up to the merid

than the one on the north or at all events more powerful So when the sun is near and at the southern tropic the warm region probably

least in force at the station and also least f vourably disposed by position But when the

gion grows up into importance by increase l strength and closer vicinity and so prod ces

west whilst at tl e latter it moves first west and then east The difference is I believe due to the appearance of nigl t cold action at St Hel ena to a greater extent tl an at Singapore Singapore shows that action in June July and August as just described (3065) but only in a weak degree and at a late hour At St Helena which is in latitude 16° S the cold effect should for tl e reasons given above (3065) appear in more power and l ence tl e eastening at 6^h and after and that tl is is the cause is indicated al so in a degree by the tables of temperature for whilst at Singapore the difference between tl e maximum and minimum in the twenty four hours is only from 3° to 4° at St Helena it is from 4° 5 to 7° and four-fifths or even five sixths of this depression occurs by 9 o clock so tl at four or five hours before that there was in the east a cold region coming up and producing the eastening effect recorded in tl e curves

3007 Th ... c

and least at mid-day it is nearly the same from 8 to 18h then as the sun comes up t decreases quickly until 23h or 24h after which as the sun passes away it increases nearly as quickly un til 7h or 8h The amount of variation is greatest when the sun is over or to the south of Su ga pore. It is least in June and July when he is near the northern trop c In December and Jan ary wh ...

... ng a maximum from 9h to 12h and a minimum at 22h or 23h near noon The greatest variation is n April and October or at the equinoxes and the least in December and June when tl e sun is at the trop es The force is the least towards noon when I suppose that the air above is in the worst cond tion of conduction and would cause a magnet in it to show more power But how that may affect the curves beneath on the surface of the earth where they are compressed together is doubtful and the whole matter of intens ty is too uncertain and has too many

Royal Institution November 16 1850

Cape of Good Hope Longitude 18° 30′ E. Latitude 33° 56′ S Declination 29° 05′ W Inclination 53° 15′ S.

Mean Diurnal variation of the Declination in each month of the years 1841 to 1846.

Increasing numbers denote a movement of the north or upper end of the *magnet towards the East*

Mean time	Noon 0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	Midn 12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
Jan	4.11	5.43	5.50	5.04	4.64	4.29	3.96	4.16	4.43	4.38	4.27	4.13	3.98	3.79	3.56	3.32	3.09	2.67	2.01	1.15	0.37	0.36	1.39	2.93	3.28
Feb.	5.51	7.48	8.21	7.86	7.06	6.11	5.74	5.83	5.90	5.82	5.74	5.69	5.78	5.73	5.56	5.50	5.38	5.27	4.90	3.36	1.26	0.00	0.52	2.96	4.93
Mar	5.34	6.74	7.29	6.93	6.17	5.48	5.32	5.33	5.42	5.39	5.28	5.40	5.34	5.52	5.59	5.54	5.52	5.39	4.95	3.22	1.04	0.02	1.26	3.44	4.66
Apr	4.07	5.00	4.76	4.21	3.75	3.53	3.42	3.39	3.44	3.45	3.51	3.56	3.53	3.98	3.96	4.07	4.17	4.32	4.15	3.29	1.32	0.00	0.39	0.06	3.30
May	1.83	2.49	2.81	2.92	2.50	2.15	2.17	2.31	2.33	2.30	2.45	2.41	2.64	2.83	2.57	3.10	3.24	3.36	3.80	3.91	2.31	0.68	0.00	0.62	2.42
June	0.74	1.27	1.87	1.87	1.36	1.05	1.11	1.19	1.24	1.34	1.49	1.63	1.74	2.00	2.04	2.25	2.22	2.28	2.59	3.21	2.38	0.86	0.00	0.10	1.58
July	0.60	1.18	1.96	2.09	1.54	1.06	1.06	1.09	1.19	1.31	1.46	1.74	2.03	2.22	2.23	2.32	2.46	2.61	3.08	3.56	2.74	1.35	0.28	0.02	1.71
Aug	0.62	1.52	2.50	3.23	2.93	2.22	2.27	2.34	2.46	2.56	2.49	2.64	2.77	2.91	3.01	3.32	3.45	3.63	4.35	4.98	3.65	1.74	0.36	0.00	2.71
Sept	1.58	2.64	3.22	3.27	2.94	2.57	2.64	2.73	2.75	2.76	2.82	2.84	2.91	3.05	3.06	3.19	3.22	3.36	4.33	4.10	2.43	0.84	0.00	0.49	2.65
Oct	4.90	5.81	5.96	5.23	4.29	3.69	3.84	4.05	4.09	4.17	4.18	4.16	4.16	4.15	3.95	3.79	3.63	3.40	2.78	1.37	0.14	0.00	1.27	3.16	3.59
Nov	5.19	6.15	6.36	5.98	5.43	4.98	5.08	5.26	5.32	5.39	5.37	5.37	5.34	5.13	4.84	4.55	4.15	3.41	2.05	0.68	0.00	0.57	2.19	3.88	4.25
Dec	4.64	5.48	5.51	5.09	4.47	4.41	4.24	4.42	4.54	4.60	4.66	4.67	4.62	4.36	4.07	3.74	3.38	2.63	1.42	0.39	0.04	0.55	2.05	3.56	3.62

Mean Diurnal variation of the Inclination in each month of the year, from April 1841 to June 1846.

Increasing numbers denote increasing inclination Inclination 53° 15′ South

Jan	0.03	0.00	0.34	0.56	0.72	1.00	1.25	1.35	1.46	1.51	1.50	1.41	1.37	1.40	1.30	1.22	1.18	1.10	0.94	0.99	0.97	0.92	0.66	0.23	0.98
Feb	0.13	0.00	0.44	1.05	1.55	1.91	2.01	2.14	2.14	2.09	2.94	1.94	1.70	1.63	1.65	1.56	1.63	1.70	1.66	1.94	2.26	2.05	1.45	0.66	1.56
Mar	0.11	0.00	0.46	1.05	1.45	1.86	2.09	2.21	2.16	2.02	1.94	1.79	1.79	1.46	1.35	1.46	1.45	1.50	1.51	1.69	1.81	1.66	1.00	0.41	1.38
Apr	0.00	0.49	1.05	1.55	1.76	1.89	2.16	2.21	2.11	2.06	1.88	1.65	1.43	1.18	1.18	1.07	1.22	1.12	1.10	1.10	1.48	1.53	0.92	0.33	1.35
May	0.00	0.38	0.70	0.86	1.08	1.16	1.27	1.31	1.49	1.59	1.39	1.32	1.16	0.89	0.93	0.89	0.76	0.68	0.30	0.15	0.53	0.66	0.56	0.12	0.84
June	0.41	0.53	0.58	0.76	0.64	0.79	0.96	1.22	1.34	1.40	1.29	1.22	1.04	0.96	0.89	0.81	0.73	0.78	0.36	0.00	0.07	0.38	0.36	0.43	0.75
July	0.62	0.64	0.59	0.64	0.77	0.87	1.18	1.20	1.46	1.43	1.43	1.21	1.07	0.95	0.77	0.87	0.67	0.60	0.28	0.00	0.18	0.51	0.64	0.56	0.80
Aug	0.12	0.38	0.76	0.99	1.16	1.27	1.34	1.60	1.55	1.52	1.45	1.30	1.16	1.04	0.84	0.83	0.63	0.68	0.27	0.00	0.13	0.33	0.43	0.30	0.84
Sept.	0.00	0.23	0.66	1.09	1.40	1.65	1.78	1.68	1.75	1.76	1.40	1.27	0.91	0.97	0.56	0.81	0.51	0.73	0.18	0.31	0.07	0.35	0.03	0.12	0.84
Oct.	0.00	0.08	0.53	1.17	1.75	1.98	1.98	1.89	1.88	1.75	1.60	1.50	1.28	1.23	1.20	1.10	1.09	1.07	1.07	1.09	1.04	0.77	0.36	0.05	1.14
Nov	0.14	0.00	0.29	0.64	1.12	1.53	1.41	1.46	1.48	1.33	1.25	1.08	0.99	0.94	0.90	0.87	0.87	0.94	0.80	0.62	0.46	0.26	0.06	0.00	0.81
Dec	0.13	0.30	0.87	1.22	1.40	1.53	1.78	2.01	2.04	1.81	1.70	1.57	1.50	1.48	1.47	1.50	1.50	1.40	1.05	0.81	0.48	0.15	0.02	0.00	1.15
Means	0.14	0.25	0.61	0.96	1.23	1.45	1.60	1.69	1.74	1.69	1.49	1.44	1.28	1.18	1.09	1.08	1.02	1.02	0.79	0.72	0.79	0.80	0.54	0.27	1.04

CAPE OF GOOD HOPE Mean Diurnal variation of the Intensity in each month of the year, from April 1841 to June 1846
Increasing numbers denote increasing intensity
The numbers express the changes in parts of the whole Force Approximate Total Intensity 7 5

Mean time	Noon 0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	Midn 12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
Jan.	000	003	018	031	041	047	048	039	036	038	040	044	045	047	049	050	052	061	071	079	078	056	028	005	042
Feb.	000	000	0 0	047	069	083	076	072	068	069	071	071	074	075	078	076	077	080	092	115	127	105	062	026	068
Mar	000	007	027	042	070	079	074	069	064	064	067	066	070	068	066	069	068	068	081	103	119	094	047	011	063
Apr	000	017	040	048	070	071	068	065	060	059	059	060	060	059	060	063	061	060	065	083	102	093	059	021	059
May	003	000	008	019	038	038	035	028	025	023	021	021	022	020	020	019	019	018	013	026	056	063	050	010	025
June	008	000	003	015	029	030	026	021	017	014	017	010	010	007	009	007	010	008	004	003	030	041	039	017	015
July	009	004	005	016	032	033	026	023	018	013	010	007	007	007	008	009	008	007	000	005	027	043	041	013	016
Aug.	008	013	007	010	028	035	029	024	019	016	017	016	016	016	017	013	013	009	000	009	044	061	064	044	023
Sept	007	000	005	015	023	028	021	017	013	012	013	012	019	015	020	014	010	008	005	018	051	057	050	023	019
Oct	000	009	033	057	070	064	053	047	045	047	047	049	051	055	056	056	056	060	073	088	084	060	025	005	050
Nov	000	005	021	038	049	057	048	044	043	044	044	047	050	053	056	057	052	074	000	096	082	054	022	007	047
Dec	000	003	015	029	037	035	034	030	027	026	028	031	035	036	038	042	047	060	074	076	066	042	013	000	034
Means	005	005	017	032	046	050	045	040	036	035	036	036	038	038	040	040	040	043	047	058	072	064	042	017	461

Mean Temperature of the Air from April 1841 to June 1846 inclusive Fahrenheit s scale

	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Jan	73 16	73 30	73 03	73 43	71 52	70 30	67 94	66 11	65 45	65 01	64 61	64 10	63 77	63 54	63 32	63 08	62 85	63 18	65 20	67 24	68 78	70 05	71 46	72 59	67 58
Feb.	74 04	74 07	73 63	72 85	71 74	70 36	68 70	66 69	66 13	65 75	65 34	64 03	64 54	64 23	64 00	63 60	63 41	63 12	64 46	66 33	67 94	69 72	71 62	73 10	67 91
Mar	71 74	72 40	72 19	71 40	69 96	68 07	65 98	64 93	64.38	63 69	63 20	62 85	62 37	62 06	61 69	61 44	61 15	60 97	61 31	63 03	65 39	67 48	69 50	71 00	65 76
Apr	68 39	68 94	68 90	69 00	66 56	64 22	62 69	62 13	61 54	60 98	60 46	59 87	59 53	59 27	59 00	58 80	58 40	58 28	59 17	59 49	61 8	64 14	65 05	67 35	62 62
May	62 32	62 55	62 43	61 74	60 49	58 99	58 05	57 41	56 61	56 39	55 65	55 48	55 37	55 21	55 05	54 81	54 59	54 32	54 04	54 44	56 42	58 48	60 09	61 79	57 61
June	58 45	58 70	58 75	58 32	57 01	55 58	54 79	54 25	53 71	53 25	52 77	52 32	52 18	51 86	51 69	51 53	51 21	50 95	50 80	50 83	52 20	54 42	56 17	57 42	54 14
July	59 15	59 66	59 65	59 71	57 7	56 13	55 15	54 47	53 83	53 34	52 86	52 37	52 08	51 72	51 42	51 19	50 96	50 83	50 51	50 88	52 67	54 94	56 87	58 28	54 41
Aug.	58 86	59 23	59 07	59 61	57 61	55 91	55 01	54 35	53 91	53 60	53 17	52 91	52 71	52 31	52 07	51 87	51 54	51 19	51 15	51 88	53 19	55 57	57 05	58 30	54 63
Sept.	61 60	61 79	61 68	60 87	59 6	58 02	56 78	56 09	55 6	55 22	54 58	54 47	54 36	53 95	53 64	53 31	53 10	53 20	53 13	54 94	56 90	58 61	59 94	60 94	56 77
Oct.	65 48	65 71	65 46	64 66	63 35	61 66	59 51	58 68	58 05	57 51	57 14	56 74	56 70	56 33	56 11	55 88	55 64	55 63	57 14	59 05	61 00	62 75	64 07	65 04	59 97
Nov	68 00	68 0	67 63	65 98	66 19	64 82	62 43	61 1	60 38	59 90	59 57	59 12	58 82	58 43	58 00	57 69	57 48	58 14	60 55	62 50	63 96	65 27	66 50	67 50	62 46
Dec.	71 02	71 23	70 84	70 21	69 64	68 23	65 69	63 94	63 19	62 64	62 07	61 59	61 18	60 82	60 49	60 17	59 91	60 83	63 41	65 80	67 17	68 42	69 62	70 42	65 35

St Helena *Longitude* 5° 40′ West Latitude 15° 56′ South Declination 23° 36′ West Inclination 21° 40′ South

Mean Diurnal variation of the Declination for the years 1841 to 1845 inclusive

Increasing numbers denote increasing eastening of *the north or upper end* of the needle Mean Declination 23° 36′ 6 W

Mean time	Noon 0^h	1^h	2^h	3^h	4^h	5^h	6^h	7^h	8^h	9^h	10^h	11^h	Midn 12^h	13^h	14^h	15^h	16^h	17^h	18^h	19^h	20^h	21^h	22^h	23^h	Daily means
	′	′	′	′		′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′	′
Jan.	3.72	3.19	2.41	2.03	2.09	1.94	1.92	2.41	2.80	2.90	2.86	2.81	2.63	2.43	2.23	2.01	1.73	1.68	1.50	0.59	0.00	0.57	1.75	3.15	2.13
Feb	4.53	4.51	4.11	3.39	2.80	2.55	2.61	3.02	3.21	3.35	3.48	3.62	3.42	3.22	3.12	2.98	2.83	2.75	2.64	1.14	0.00	0.31	1.52	3.34	2.85
Mar	3.76	4.11	3.48	2.57	2.15	2.20	2.48	2.64	2.69	2.68	2.85	2.84	2.80	2.77	2.68	2.70	2.69	2.70	2.96	1.90	0.26	0.00	1.13	2.72	2.49
Apr	3.28	2.48	1.05	1.27	1.03	1.01	1.23	1.50	1.56	1.60	1.71	1.81	1.96	1.92	1.92	2.00	2.16	2.22	2.47	2.15	0.62	0.00	0.82	2.57	1.70
May	0.71	0.44	0.57	0.71	0.55	0.21	0.25	0.48	0.56	0.72	0.78	0.90	1.02	1.09	1.11	1.18	1.32	1.57	2.04	2.58	1.50	0.32	0.00	0.49	0.88
June	0.71	0.73	0.88	0.94	0.44	0.00	0.10	0.39	0.56	0.73	0.90	1.06	1.17	1.22	1.25	1.29	1.40	1.66	2.16	3.31	2.69	1.39	0.75	0.69	1.10
July	0.82	0.71	0.78	0.84	0.48	0.02	0.00	0.22	0.46	0.64	0.84	0.98	1.08	1.14	1.14	1.24	1.31	1.46	2.02	3.11	2.58	1.31	0.63	0.67	1.02
Aug	0.11	0.00	0.40	0.66	0.82	0.42	0.25	0.52	0.68	0.78	0.88	1.02	1.02	1.02	1.04	1.18	1.27	1.61	2.37	3.43	2.52	1.19	0.36	0.05	0.99
Sept	0.89	0.85	0.65	0.44	0.35	0.28	0.28	0.53	0.62	0.67	0.79	0.78	0.75	0.64	0.61	0.65	0.70	0.95	2.12	1.89	0.55	0.17	0.00	0.43	0.70
Oct.	4.41	4.35	3.43	2.06	1.23	1.32	1.80	2.04	2.21	2.34	2.45	2.43	2.23	2.00	1.92	1.81	1.72	1.74	1.99	0.49	0.00	0.72	2.09	3.61	2.10
Nov	3.97	3.82	3.31	2.52	1.85	1.85	2.29	2.77	2.99	3.13	3.21	3.12	2.96	2.68	2.46	2.23	1.97	1.80	1.63	0.21	0.00	1.03	2.22	3.41	2.39
Dec	3.65	3.48	2.70	1.94	1.68	1.85	2.15	2.58	2.93	3.12	3.20	3.13	2.89	2.64	2.40	2.17	1.93	1.73	1.38	0.32	0.00	0.86	2.09	3.32	2.25

Mean Diurnal variation of the Inclination in each month, from January 1841 to December 1845.

Increasing numbers denote increasing inclination Mean Inclination 21° 40′ *South*

Jan	0.14	0.46	1.07	1.49	2.18	2.53	2.77	2.91	2.87	2.83	2.77	2.63	2.40	2.23	1.99	1.85	1.80	1.77	1.65	1.37	0.88	0.53	0.00	0.02	1.71
Feb	0.23	0.61	1.33	2.00	2.39	2.78	3.01	3.15	3.12	2.98	2.88	2.73	2.61	2.46	2.44	2.21	2.15	2.00	2.04	1.82	1.40	0.94	0.10	0.00	1.97
Mar	0.11	0.56	1.33	1.86	2.21	2.47	2.80	2.97	2.99	2.89	2.89	2.67	2.46	2.37	2.26	2.12	1.99	2.01	1.84	1.53	1.06	0.43	0.00	0.10	1.83
Apr	0.45	0.89	1.54	2.14	2.53	2.83	3.05	3.17	3.26	2.88	2.97	2.63	2.41	2.18	2.15	2.08	1.68	1.77	1.47	1.30	0.94	0.43	0.27	0.00	1.88
May	0.20	0.74	1.16	1.62	1.90	2.10	2.22	2.36	2.28	2.21	2.12	1.99	1.77	1.69	1.56	1.33	1.21	1.16	1.18	1.09	0.81	0.36	0.00	0.03	1.38
June	0.18	0.56	1.04	1.58	1.65	1.91	2.21	2.26	2.24	2.12	2.02	1.98	2.06	1.77	1.68	1.54	1.46	1.36	1.22	0.98	0.80	0.43	0.09	0.00	1.39
July	0.30	0.60	1.06	1.44	1.82	2.01	2.42	2.47	2.40	2.35	2.21	2.04	1.80	1.68	1.62	1.30	1.25	1.08	1.00	0.84	0.53	0.27	0.00	0.03	1.35
Aug	0.25	0.72	1.21	1.61	1.94	2.16	2.35	2.40	2.39	2.19	2.12	1.98	1.80	1.69	1.58	1.40	1.33	1.25	1.13	1.07	0.79	0.54	0.19	0.00	1.42
Sept	0.13	0.70	1.29	1.72	2.02	2.19	2.40	2.40	2.32	2.13	2.01	1.99	1.80	1.68	1.47	1.50	1.51	1.44	1.40	1.27	0.92	0.60	0.36	0.00	1.47
Oct	0.24	0.74	1.36	1.90	2.34	2.56	2.55	2.88	2.65	2.56	2.46	2.28	2.09	2.04	1.89	1.80	1.70	1.69	1.63	1.31	0.88	0.37	0.00	0.02	1.66
Nov	0.08	0.27	0.74	1.19	1.63	2.00	2.35	2.45	2.38	2.30	2.18	2.07	1.96	1.83	1.71	1.59	1.66	1.48	1.35	0.92	0.55	0.23	0.00	0.10	1.33
Dec	0.26	0.73	1.06	1.59	2.08	2.41	2.69	2.78	2.61	2.45	2.39	2.15	2.01	1.80	1.72	1.56	1.48	1.38	1.26	0.85	0.40	0.10	0.00	0.07	1.49
Means	0.22	0.63	1.18	1.69	2.06	2.33	2.57	2.68	2.63	2.49	2.42	2.26	2.10	1.94	1.83	1.69	1.62	1.53	1.43	1.20	0.83	0.44	0.08	0.03	1.58

St Helena Mean Diurnal variation of the Total Intensity in each month, from January 1841 to December 1845

Increasing numbers denote increasing intensity

Mean time	Noon 0h	1h	2h	3h	4h	5h	6h	7h	8h	9h	10h	11h	M dn. 12h	13h	14h	15h	16h	17h	18h	19h	20h	21h	22h	23h	Daily means
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
Jan.	130	129	116	005	081	063	046	027	016	004	000	001	001	008	015	015	019	010	074	040	055	080	109	124	051
Feb	117	108	082	077	063	050	029	014	007	001	002	003	004	002	000	002	002	003	009	023	046	070	095	114	039
Mar	153	147	124	066	070	055	032	020	010	000	006	004	001	016	014	018	018	021	026	040	068	102	132	149	055
Apr	162	150	122	086	068	042	021	010	005	001	004	000	007	014	015	016	025	024	024	031	054	000	102	150	051
May	163	142	115	087	065	049	036	023	016	011	004	000	008	008	011	018	019	019	075	034	048	095	132	150	054
June	141	128	101	064	063	047	028	015	006	004	001	000	002	003	004	004	004	009	013	022	042	075	110	137	043
July	126	117	095	073	051	042	027	015	011	002	002	000	003	005	006	011	015	018	019	024	038	068	097	116	041
Aug.	139	126	103	077	053	038	026	013	004	001	000	000	002	005	009	015	015	016	016	018	037	068	103	131	039
Sept	143	131	105	077	056	037	026	013	004	000	003	007	011	014	018	024	022	024	023	022	038	069	101	134	046
Oct.	135	123	105	088	070	051	030	015	007	001	000	005	011	013	019	020	019	020	017	032	058	093	123	135	050
Nov	112	111	101	090	076	055	029	018	007	000	002	009	011	011	016	017	017	017	026	048	071	087	105	112	048
Dec	116	110	105	089	071	051	027	011	004	000	003	003	003	006	008	010	011	012	024	046	064	086	107	117	045
Means	126	127	107	084	066	048	330	016	008	002	002	003	006	009	011	014	015	017	021	032	052	082	110	132	047

Mean Temperature of the Air from 1841 to 1845 inclusive

	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Jan.	67 68	68 05	67 03	67 79	67 30	66 04	64 58	63 39	62 93	62 82	62 42	62 27	62 06	61 88	61 66	61 60	61 49	61 39	61 37	61 84	62 79	64 09	65 38	66 55	63 98
Feb	69 14	69 61	69 85	69 50	68 95	67 89	66 59	65 43	64 91	64 66	64 46	64 32	64 13	63 96	63 78	63 59	63 51	63 44	63 42	63 62	64 43	65 77	67 08	68 24	65 87
Mar	69 13	69 57	69 89	69 71	69 10	68 10	66 86	65 84	65 47	65 15	65 00	64 83	64 65	64 50	64 31	64 17	64 15	64 03	64 05	64 29	65 08	66 39	67 35	68 38	66 24
Apr	68 54	68 80	68 98	68 64	67 99	66 98	65 84	65 16	64 84	64 61	64 45	64 29	64 11	64 02	63 88	63 77	63 66	63 51	63 49	63 69	64 50	65 70	66 74	67 86	65 60
May	65 76	66 01	66 00	65 84	65 17	64 11	63 56	63 32	62 73	62 13	62 03	61 88	61 67	61 57	61 40	61 24	61 19	61 19	61 04	61 06	62 01	63 22	64 11	65 22	63 05
June	62 40	62 78	62.73	62 39	61 83	60 98	60 14	59 68	59 49	59 34	59 20	59 11	59 00	58 86	58 74	58 61	58 58	58 53	58 47	58 52	59 13	60 16	60 98	61 80	60 07
July	60 37	60 83	60 77	60 51	59 87	58 98	58 14	57 70	57 48	57.25	57 13	56 91	56 81	56 72	56 60	56 51	56 43	56 36	56 31	56 38	57 07	58 09	58 90	59 69	57 99
	59 08	59 90	60 12	59 72	59 11	58 11	57 23	56 83	56 60	56 45	56 32	56 20	56 10	55 98	55 76	55 68	55 53	55 50	55 39	55 56	56 20	57 22	58 07	58 96	57 17
	59 80	60 26	60 18	59 77	59 11	58 03	57 05	56 86	56 35	56 21	56 04	55 91	55 82	55 67	55 51	55 37	55 29	55 21	55 21	55 44	56 12	57 18	58 31	59 14	57 07
	61 80	61 98	61 91	61 31	60 46	59 31	58 18	57 57	57 64	57 12	56 99	56 84	56 64	56 48	56 30	56 19	56 11	56 01	56 06	56 50	57 35	58 61	59 71	60 73	58 23
	63 44	63 88	63.97	63 52	62 63	61 32	59 84	59 11	58 78	58 57	58 41	58 24	58 08	57 90	57 71	57 62	57 55	57 43	57 53	58 03	58 94	60 20	61 35	62 35	59 84
	65 19	65 81	65 87	65 72	64 88	63 82	62 17	61 10	60 70	60 48	60 27	60 12	59 95	59 75	59 57	59 47	59 34	59 31	59 39	59 77	60 69	61 97	63 03	64.19	61 77

Singapore Latitude 1° 16′ N Longitude 103° 53′ E Declination 1° 40′ E (Approx) Inclination 12° S (Approx)

Mean Hourly oscillation of the Magnetic Declination for each month of the years 1843, 1844 and 1845

Increasing numbers denote a movement of the north or upper end of the magnet towards the East

	Noon 0¼h	1¼h	2¼h	3¼h	4¼h	5¼h	6¼h	7¼h	8¼h	9¼h	10¼h	11¼h	Midn 12¼h	13¼h	14¼h	15¼h	16¼h	17¼h	18¼h	19¼h	20¼h	21¼h	22¼h	23¼h	Daily means
	′	′	′	′	′	′	′	′	′	′	′	′	′		′	′	′	′	′	′	′	′	′	′	′
an	2.04	2.52	2.79	2.72	2.52	2.24	2.11	2.18	2.04	1.97	1.84	1.70	1.63	1.63	1.50	1.43	1.29	1.02	0.61	0.00	0.00	0.41	0.82	1.22	1.59
eb	2.31	2.92	3.13	3.06	2.79	2.52	2.31	2.31	2.18	2.04	1.90	1.90	1.97	1.90	1.90	1.90	1.84	1.70	1.29	0.54	0.00	0.00	0.34	1.43	1.84
Mar	1.29	1.43	1.63	1.77	1.63	1.43	1.29	1.09	0.95	0.88	0.52	0.82	0.88	0.88	0.88	0.82	0.82	0.82	0.82	0.48	0.00	0.07	0.54	1.02	0.96
Apr	0.34	0.61	0.75	1.02	1.16	1.16	0.95	0.82	0.61	0.54	0.61	0.68	0.82	0.95	0.95	0.95	0.88	0.82	1.16	0.95	0.34	0.00	0.20	0.41	0.70
May	0.07	0.48	0.82	1.16	1.36	0.95	1.02	0.88	0.75	0.68	0.75	0.82	1.09	1.16	1.29	1.36	1.36	1.43	2.11	2.24	1.43	0.68	0.27	0.00	0.75
June	0.20	0.41	0.54	0.61	0.54	0.34	0.14	0.00	0.00	0.00	0.07	0.20	0.41	0.54	0.61	0.68	0.68	0.82	1.36	1.56	0.82	0.41	0.00	0.14	0.46
July	0.07	0.41	0.61	0.88	1.02	0.88	0.48	0.34	0.27	0.20	0.27	0.34	0.54	0.68	0.82	0.75	0.82	1.16	1.63	1.97	1.29	0.54	0.14	0.00	0.67
Aug	0.20	0.68	1.02	1.56	1.63	1.84	1.43	1.29	1.09	1.02	1.02	1.16	1.22	1.36	1.43	1.50	1.50	1.70	2.52	2.79	1.77	0.75	0.14	0.00	1.27
Sept.	0.48	0.88	1.36	1.63	1.63	1.56	1.50	1.29	1.16	1.09	1.02	1.09	1.16	1.22	1.29	1.29	1.36	1.43	1.97	1.77	0.75	0.20	0.00	0.20	1.14
Oct	1.00	2.31	2.31	2.18	1.97	1.77	1.77	1.63	1.50	1.36	1.29	1.29	1.43	1.36	1.36	1.29	1.22	1.09	1.16	0.54	0.14	0.00	0.27	1.02	1.33
Nov	2.45	2.92	2.99	2.86	2.45	2.11	1.97	1.84	1.70	1.56	1.36	1.36	1.43	1.43	1.36	1.29	1.16	1.02	0.48	0.00	0.00	0.27	0.82	1.63	1.51
Dec	2.52	2.99	2.99	2.99	2.86	2.45	2.18	2.04	1.97	1.84	1.70	1.63	1.56	1.56	1.56	1.50	1.43	1.16	0.61	0.00	0.00	0.41	1.02	1.77	1.70

Mean Diurnal variation of the Inclination in the several months during the years 1843 1844 and 1845

Increasing numbers denote increasing inclination Approximate inclination 12° South

	Noon 0¼h	1¼h	2¼h	3¼h	4¼h	5¼h	6¼h	7¼h	8¼h	9¼h	10¼h	11¼h	Midn 12¼h	13¼h	14¼h	15¼h	16¼h	17¼h	18¼h	19¼h	20¼h	21¼h	22¼h	23¼h	Daily means
Jan	0.00	0.43	0.98	1.28	1.00	2.07	2.38	2.57	2.62	2.71	2.76	2.76	2.66	2.71	2.71	2.72	2.72	2.72	2.73	2.52	1.97	1.09	0.32	0.02	1.97
Feb	0.04	0.64	1.24	1.75	2.00	2.21	2.56	2.82	2.94	3.02	3.10	3.07	3.08	3.03	2.98	2.99	2.97	2.97	3.03	2.88	2.35	1.21	0.40	0.00	2.22
Mar	0.08	0.29	0.75	1.36	1.75	1.88	2.22	2.55	2.65	2.70	2.74	2.72	2.72	2.67	2.71	2.72	2.72	2.75	2.75	2.54	1.84	0.75	0.11	0.00	1.91
Apr	0.28	0.82	1.54	2.09	2.47	2.71	3.04	3.00	3.27	3.36	3.41	3.49	3.43	3.40	3.33	3.29	3.29	3.27	3.15	2.92	2.18	1.15	0.28	0.00	2.46
May	0.00	0.32	0.50	1.17	1.62	1.96	2.29	2.34	2.42	2.43	2.42	2.20	2.38	2.40	2.42	2.46	2.52	2.51	2.25	1.87	1.25	0.49	0.03	0.00	1.69
June	0.04	0.20	0.57	0.98	1.44	1.50	2.20	2.25	2.19	2.16	2.10	2.07	2.15	2.21	2.15	2.20	2.21	2.29	2.02	1.71	1.25	0.69	0.22	0.00	1.53
July	0.00	0.15	0.45	0.89	1.34	1.76	2.10	2.16	2.19	2.20	2.20	2.07	2.18	2.19	2.19	2.21	2.21	2.27	2.02	1.74	1.28	0.69	0.27	0.05	1.53
Aug	0.12	0.34	0.69	1.01	1.35	1.68	1.99	2.32	2.21	2.27	2.26	2.28	2.26	2.20	2.18	2.22	2.21	2.22	1.93	1.68	1.30	0.62	0.14	0.00	1.56
Sept	0.41	1.00	1.60	1.94	2.11	2.72	2.58	2.69	2.78	2.82	2.83	2.84	2.85	2.79	2.74	2.75	2.75	2.79	2.66	2.39	1.66	0.79	0.15	0.00	2.09
Oct	0.38	1.17	1.94	2.38	2.48	2.59	2.56	3.07	3.23	3.29	3.34	3.23	3.33	3.23	3.22	3.20	3.24	3.20	3.25	2.96	2.18	1.14	0.21	0.00	2.46
Nov	0.16	0.63	1.37	1.96	2.32	2.68	2.88	2.87	3.02	3.08	3.07	3.06	3.06	3.03	3.02	2.95	3.01	3.00	3.15	2.80	2.01	1.04	0.17	0.00	2.26
Dec	0.09	0.54	1.13	1.62	1.92	2.26	2.53	2.66	2.85	2.86	2.85	2.86	2.76	2.76	2.72	2.69	2.65	2.69	2.44	2.38	1.81	1.08	0.34	0.00	2.02
Means	0.13	0.54	1.09	1.54	1.89	2.14	2.47	2.61	2.70	2.74	2.76	2.72	2.74	2.72	2.70	2.70	2.71	2.72	2.62	2.37	1.70	0.89	0.22	0.01	1.98

SINGAPORE Mean Diurnal variation of the Total Intensity in the several months during the years 1843 1844 1845
Increasing numbers indicate increase of total intensity
The numbers express the changes in parts of the whole force Approximate total intensity 8 21

Mean time	Noon 0¼h	1¼h	2¼h	3¼h	4¼h	5¼h	6¼h	7¼h	8¼h	9¼h	10¼h	11¼h	Mid 12¼h	13¼h	14¼h	15¼h	16¼h	17¼h	18¼h	19¼h	20¼h	21¼h	22¼h	23¼h	Daily means
	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
Jan	056	066	047	040	0 8	071	015	009	009	003	002	000	007	002	008	007	010	012	022	033	054	074	0 9	100	031
Feb.	090	080	061	042	027	024	013	009	004	000	000	002	000	001	005	005	009	011	014	025	049	082	104	110	032
Mar	114	085	055	035	0 6	020	013	007	003	001	000	002	005	008	007	009	011	012	012	0 7	057	087	112	122	035
Apr	1 2	094	005	040	0 0	090	016	011	005	003	005	002	000	004	009	011	013	015	0 0	043	076	110	139	137	041
May	104	091	000	0 8	0 0	015	014	011	010	008	008	000	004	005	006	008	003	012	025	014	073	097	114	118	036
June	096	075	0 1	026	011	012	004	004	001	000	000	000	001	001	003	004	004	008	020	038	062	085	102	105	031
July	100	081	066	033	019	013	007	007	004	034	002	000	002	004	008	004	010	015	026	044	070	091	105	110	034
Aug	101	081	055	0 3	016	009	010	005	006	000	002	002	004	010	011	011	016	018	028	046	077	096	115	114	036
Sept	093	065	037	020	018	009	009	008	002	001	000	003	003	008	014	018	019	017	023	045	079	104	117	115	035
Oct	109	073	040	036	029	024	013	007	003	000	000	001	006	011	011	016	019	017	020	037	070	101	117	121	037
Nov	080	063	014	030	021	015	009	003	001	000	001	000	002	006	007	013	012	013	017	034	059	082	098	095	029
Dec	077	061	044	031	026	071	012	004	000	006	001	002	003	006	009	013	014	014	019	035	056	078	095	091	030
Means	093	075	052	033	022	010	011	007	004	002	002	001	003	006	008	010	012	014	021	038	065	091	110	112	034

Mean Temperature of the Air observed on the Standard Thermometer inside the Observatory, during the years 1841, 1842 and 1843

	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°	°
Jan.	79 7	79 5	80 0	79 5	79 7	79 1	79 0	78 4	78 5	79 0	78 1	77 5	77 9	77 3	77 6	78 9	77 4	78 5	77 0	76 3	77 3	77 4	78 6	78 8	78 2
Feb.	80 7	81 0	81 2	80 1	81 2	80 1	80 2	80 6	79 7	80 2	79 2	79 6	78 6	79 0	78 3	78 6	78 2	78 2	77 7	78 2	78 0	79 4	79 6	81 8	79 8
Mar	81 4	82 1	81 7	80 3	81 6	82 0	80 9	81 5	80 5	81 2	80 1	81 0	79 9	80 6	79 4	80 3	79 1	79 9	78 7	79 8	79 4	80 6	80 6	81 5	80 7
Apr	81 8	81 8	80 1	81 3	81 9	81 8	81 4	81 2	81 0	80 0	80 7	80 2	80 3	80.3	79 9	80 0	79 5	79 6	79 2	79 8	79 9	80 6	81 1	81 4	80 8
May	82 3		82 7		82.5		82 1		81 8		81 4		80 9		80 5		80 3		79 9		80 9		81 8		81 4
June	82 3	8_3	82 7	83 1	82 5	82 7	82 2	82 0	81 7	81 6	81 4	81 4	81 2	81 2	80 7	80 7	80 3	80 ?	80 1	80 4	81 0	81 7	81 8	82 6	81 6
July	82 4	83 0	82 8	83 1	82 7	82 7	82.2	82 1	81 8	81 9	81 5	81 5	81 1	81 2	80 7	80 9	80 3	80 6	80 8	80 8	80 8	81 9	81 9	82 6	81 7
Aug.	81 7	81 0	81 9	81 0	81 8	81 8	81 4	81 3	81 0	81 2	80 8	80 8	80 4	80 3	80 1	80 1	79 8	79 8	79 5	79 8	80 2	80 8	81 2	81 6	80 0
Sept.	82 1	82 8	82 4	82 3	82 2	82 1	81 7	81 6	81 5	81 2	81 0	80 8	80 5	80 3	80 1	80 0	79 7	79 7	79 4	79 4	80 3	80 9	81 4	81 8	81 0
Oct.	81 5	81 3	81 7	81 4	81.7	81 2	81 2	80 6	80 7	80 2	80 1	79 8	79 6	79 8	79 4	79 3	79 0	79 3	78 7	79 2	79 5	80 0	80 7	80 9	80 3
Nov	81 1	81 0	81 3	80 8	81 0	80 6	80 4	80.1	80 1	79 7	79 7	79 6	79 3	79 1	78 9	78 7	78 6	78 5	78 4	78 5	79 2	79 6	80 2	80 5	79 8
Dec	81 0	81 3	81 3	81 3	80 9	80 8	80 1	80 0	79 6	79 4	79 2	79 2	79 0	79 0	78 6	78 4	78 1	78 1	77 9	78 2	78 7	79 5	80 1	80 7	79 6
Means	81 5	81 7	81 5	81 8	81 6	81 5	81 1	80 9	80 7	80 5	80 3	80 1	79 9	79 8	79 5	79 4	79 2	79 1	78 9	79 1	79 6	80 2	80 7	81 3	80 4

TWENTY-EIGHTH SERIES[1]

§ 34. *On Lines of Magnetic Force, their Definite Character; and their Distribution within a Magnet and through Space*

RECEIVED OCTOBER 22, READ NOVEMBER 27 AND DECEMBER 11, 1851

3070 FROM my earliest experiments on the relation of electricity and magnetism (114 *note*), I have had to think and speak of lines of magnetic force as representations of the magnetic power, not merely in the points of quality and direction, but also in quantity The necessity I was under of a more frequent use of the term in some recent researches (2149, &c), has led me to believe that the time has arrived, when the idea conveyed by the phrase should be stated very clearly, and should also be carefully examined, that it may be ascertained how far it may be truly applied in representing magnetic conditions and phenomena; how far it may be useful in their elucidation; and, also, how far it may assist in leading the mind correctly on to further conceptions of the physical nature of the force, and the recognition of the possible effects, either new or old, which may be produced by it

is no tendency to the formation of any current in the wire, whilst if moved in any other

The direction of these lines about and amongst magnets and electric currents, is easily repre-

of the ends of the magnetic needle, or by the direction of the current induced in the moving wire

3073 A point equally important to the definition of these lines is that they represent a determinate and unchanging amount of force Though, therefore, their forms, as they exist between two or more centres or sources of magnetic power, may vary very greatly, and also the space through which they may be traced,

however convergent or divergent they may be at the second place The experimental proof of this character of the lines will be given hereafter (3109, &c)

od which represents the forces as concentrated in centres of action, such as the poles of magnets or needles; or some other methods, as, for

plied But some may, by their very nature, be applicable to a far greater extent, and give far more varied results, than others For just as either geometry or analysis may be employed to solve correctly a particular problem, though one has far more power and capability, gener-

of centres, or that of the disposition of magnetic fluids or that of lines of force, be applied in the consideration of magnetic phenomena It is the occasional and more frequent use of the latter which I at present wish to advocate

3075 I des...

the physical cause of the phenomena, or be tied up with, or in any way dependent on such an idea Still, there is no impropriety in endeavouring to conceive the method in which the physical forces are either excited, or exist, or are transmitted, nor, when these by experiment and comparison are ascertained in any given degree, in representing them by any method which we adopt to represent the mere forces provided no error is thereby introduced On the contrary, when the natural truth and the conventional representation of it most closely agree then are we most advanced in our knowledge The emission and the ether theories present such cases in relation to light The idea of a fluid or of two fluids is the same for electricity, and there the further idea of a current has been raised, which indeed has such hold on the mind as occasionally to embarrass the science as respects the true character of the physical agencies, and may be doing so, even now, to a degree which we at present little suspect The same is the case with the idea of a magnetic fluid or fluids, or with the assumption of magnetic centres of action of which the resultants are at the poles How the magnetic force is transferred through bodies or through space we know not —whether the result is merely action at a distance, as in the case of gravity, or by some intermediate agency, as in the cases of light, heat the electric current, and (as I believe) static electric action The idea of magnetic fluids as applied by some, or of magnetic centres of action, does not include that of the latter kind of transmission, but the idea of lines of force does ...

the most ...

of magnetic phenomena external to the magnet, I am more inclined to the notion that in the transmission of the force there is such an action, external to the magnet, than that the effects are merely attraction and repulsion at a distance Such an action may be a function of the ether for it is not at all unlikely that, if there be an ether, it should have other uses than simply the conveyance of radiations (2591, 2787) Perhaps when we are more clearly instructed in this matter, we shall see the source of the contradictions which are supposed to exist between the results of Coulomb, Harris and other philosophers, and find that they are not contradictions in reality, but mere differences in degree, dependent upon partial or imperfect views of the phenomena and their causes

3076 Lines of magnetic force may be recognized, either by their action on a magnetic needle, or on a conducting body moving across them Each of these actions may be employed also to indicate either the direction of the line, or the force exerted at any given point in it, and this they do with advantages for the one method or the other under particular circumstances The actions are however very different in their nature The needle shows its results by attractions and repulsions, the moving con-...

and other reasons I propose to develop and apply the method by a moving conductor on the present occasion

3077 The general principles of the development of an electric current in a wire moving under the influence of magnetic forces, were ... former ... the first ...

when moving in places of equal action, i e., transversely across the lines of force (217)

3079 It determines the direction of the polarity by an effect entirely independent of pointing or such like results of attraction or repulsion i e, by *the direction of the electric current*

bodies as the metals as well as outside in the air It is not often embarrassed by the differ-

the needle is forbidden and in other cases where the needle might be resorted to though greatly embarrassed by the media around it the moving wire may be used with an immediate result (3142)

3081 The method can even be applied with equal facility to the interior of a magnet (3116) a place utterly inaccessible to the magnetic needle

3082 The moving wire can be made to sum up or give the resultant at once of the magnetic *action at many different places* i e, the action due to an area or section of the lines of force and so supply experimental comparisons which the needle could not give except with very great labour and then imperfectly Whether the wire moves directly or obliquely across the lines of force, *in one direction or another* it sums up with the same accuracy in principle the amount of the forces represented by the lines it has crossed (3113)

e l out in the present paper and though its

those which are active in the other I mean as far as we have been able as yet to refer directly

¹ A natural standard of this polar ty may be ob-

the effects to essential characters and this difference may hereafter enable the wire to give a new insight into the nature of the magnetic force and so it may *finally* bear upon inquiries such as whether magnetic polarity is axial or dependent upon transverse lateral conditions whether the transmission of the force is after the manner of a vibration or current or simply action at a distance and the many other questions that arise in the minds of those who are pursuing this branch of knowledge

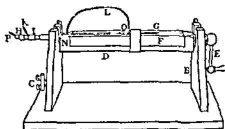


Fig 1

pose of ascertaining how these lines of force are disposed both without and within the magnet

board 17.5 inches in length and 6 inches in breadth and 0 8 of an inch in thickness these dimensions will serve as a scale for the other parts A B are two wooden uprights D is an axis

so as to form a notch between the two magnets when they are in their places and by further removal of the wood this notch is continued on to the end of the axis at P This notch or opening is intended to receive a wire which can be carried down the axis of rotation and then passing out between the two magnets, anywhere between O and N can be returned towards the end P on the outside The magnets are so placed that the central line of their compound system coincides with the axis of rotation E being a handle by which rotation when

required, is given H and I are two copper rings, slipping tightly on to the axis, by which communication is to be made between a wire adjusted so as to revolve with the magnets, and the fixed ends of wires proceeding from a galvanometer Thus, let P L represent a covered

ring I is put into its place, it shall press upon the

separated The second ring, H, is then put into its place on the axis, and the introduction of a small wedge of wood, at the end of the axis, serves to press the end P into close and perfect contact with the ring H, and keep all in order

galvanometer wire (also of copper), and the latter are made to press against the rings by their elasticity, and give an effectual contact bearing, which generates no current either by difference of nature or by friction, during the revolution of the axis

3085 The two magnets are bars, each 12 inches long 1 inch broad, and 0 4 of an inch thick They weigh each 19 ounces, and are of such a strength

strument made by Rhumkorff (2651) It was placed about 6 feet from the magnet apparatus, and was not affected by any revolution of the latter

The condition of the galvanometer, wires, and magnets, was such, that when the bend of the wires was formed into a loop, and that carried once over the pole of the united magnets, as from *a* to *b*, *Fig 2*, the galvanometer needle was deflected two degrees or more The vibration of the needle was slow, and it was easy therefore to reiterate this action five or six times, or oftener, breaking and making contact with the galvanometer at right intervals, so as to combine the effect of like induced currents and then a deflection of 10° or 15° on either side of zero could be readily obtained The arrangement, therefore, was sufficiently sensible for first experiments, and though the resistance opposed by the thin long galvanometer wire to feeble currents was considerable, yet it would always be the same, and would not interfere with results, where the final effect was equal to 0°, nor in those where the consequences were shown, not by absolute measurement, but by comparative differences

3087 The first practical result produced by the apparatus described in respect of magneto-electric induction generally, is that a piece of metal or conducting matter which moves across

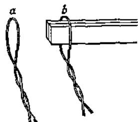


Fig 2

lines of magnetic force has, or tends to have, a current of electricity produced in it A more restricted and precise expression of the full effect is the following If a continuous circuit of conducting matter be traced out, or conceived of, either in a solid or fluid mass of metal or conducting matter, or in wires or bars of metal arranged in non-conducting matter or space, which being moved, crosses *lines of magnetic* force, or being still, is by the translation of a magnet *crossed* by such lines of force, and

3088 Thus, if *Fig 3* represent a magnetic pole N, and over it a circuit, formed of metal, which may be of any shape, and which is at first in the position *c*, then if that circuit be moved in one direction into the position 1, or in the contrary direction into position 2, or by a double direction of motion into position 3, or by translation into position 4, or into position 5, or any position between the first and these or any resembling them, or, if the first position *c* being retained, the pole moved to or towards, the position *n*, then, an electric current will be

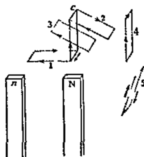


Fig 3

3089 The general principles of the production of electrical currents by magnetic induction have been formerly given (27, &c),[1] and the law of the direction of the current in relation to the lines of force, stated (114, 3079 *note*) But the full meaning of the above description can only be appreciated hereafter, when the experimental results, which supply a larger knowledge of the relations of the current to the *lines of force*, have been described

3090 When *lines of force* are spoken of as crossing a conducting circuit (3087), it must be considered as effected by the *translation* of a magnet No mere *rotation* of a bar magnet on its axis, produces any induction effect on circuits exterior to it, for then, the conditions above described (3088) are not fulfilled The system of power about the magnet must not be considered as necessarily revolving with the magnet, any more than the rays of light which emanate from the sun are supposed to revolve with the sun The magnet may even, in certain

3091 In the first instance the wire was carried down the axis of the magnet to the middle distance, then led out at the equatorial part, and returned on the outside, *Fig 4* will repre-



Fig 4

sent such a disposition Supposing the magnet and wire to revolve once, it is evident that the wire *a* may be considered as passing in at the

lines of force emanating from the N end of the magnet In other words, whatever course the wire may take from *b* to *c*, the whole system of lines belonging to the magnet has been *once* crossed by the wire In order to have a correct notion of the relation of the result, we will suppose a person standing at the handle E, *Fig 1* (3084), and looking along the magnets, the magnets being fixed, and the wire loop from *b* to *c* turned over toward the left-hand into a horizontal plane, then, if that loop be moved over towards the right hand, the magnet remaining stationary, it will be equivalent to a *direct* revolution (according to the hands of a watch or

will produce a corresponding current in the reverse direction to the former If the wire be held in a vertical, or any other plane, so that it may be considered as fixed, and the magnet be rotated through half a revolution, it will also produce *a current, and if rotated in the contrary* direction, will produce a contrary current but as to the *direction* of the currents, that produced by the *direct* revolution of the wire is the same *as that produced by the reverse revolution of the* magnet, and that produced by the *reverse* revolution of the wire is the same as that produced

any, could be greatly exalted, because the rotation could be continued for 10, 20, or any number of revolutions without derangement, and it was easy to make thirty revolutions or more within the time of the swing of the galvanometer needle in one direction It was also easy, if any effect were produced, to accumulate it upon the galvanometer by reversing the rotation at the due time But no amount of revolution of the magnet and wire together could produce any effect

3093 The loop was then taken out of the axis of the magnet, but attached to it by a piece of pasteboard, so that all should be fixed together and revolve with the same angular velocity, *Fig 5*, but whatever the shape or dis-



Fig 5

position of the loop, whether large or small, near or distant, open or shut, in one plane, or contorted into various planes, whatever the shape or condition, or place, provided it moved altogether with the magnet, no current was produced

3094 Furthermore, when the loop was out of the magnets, and by expedients of arrangement, was retained immoveable, whilst the magnet revolved, no amount of rotation of the magnet (unaccompanied by translation of place) produced any degree of current through the loop

3095 The loop of wire was then made of two parts, the portion *c*, *Fig 6*, on the outside of the

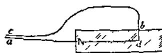


Fig 6

magnet, was fixed at *b*, and the portion *a*, being a separate piece, was carried along the axis until it came in contact with the former at *d*, the revolution of one part was thus permitted either with or without the other, yet preserving always metallic contact and a complete circuit for the induced current In this case, when the external wire and the magnet were fixed, *no* current was produced by any amount of revolution of the wire *a* on its axis Neither was any current produced when the magnet and wire, *c d*, were revolved together, whether the wire *a* revolved with them or not When the magnet was revolved without the external part of *c d*, or the latter revolved without the magnet, then currents were produced as before (3091).

[illegible]

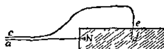


Fig 7

[illegible]

parts of the magnet in place of an insulated copper wire, for the completion of the circuit in which the induced current was to travel No rotation of the part *a* produced any effect, where- [illegible]

wire, a copper ring was fixed round, and in contact with it at the equatorial part, and the wire c, *Fig 8*, made to bear by spring pressure against

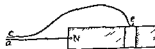


Fig 8

[illegible]

and the results when the wire and magnet rotated together (3092), show that these are in amount exactly equal to the former When the inner and the outer wires were both motionless, and the magnet only revolved, a current in the full proportion was produced, and that, whether the axial wire *a* made contact at the pole of the magnet or in the centre

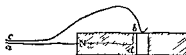


Fig 9

ference *b*, being connected there with the equatorial ring (3097), an axial wire touched this radial wire at the centre and passed out at the pole, the external part of the circuit, pressing on the ring at the equator, proceeded on the outside over the pole to form the communication as before In the case where the magnet was revolved without the axial and the external wire, the full and proper current was produced, the small wire, *d b*, being however, the only part in which this current could be generated by the motion for it replaced, under these circumstances, the body of the magnet employed on the former occasion (3097)

3099 The external part of the wire instead of being carried back over that pole of the magnet at which the axial wire entered, was con-

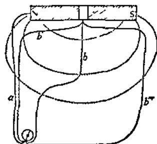


Fig 10

same, for if *a* be the axial wire, and *b′*, *b″*, *b‴* the equatorial wire, represented in three different positions, whatever magnetic lines of force pass across the latter wire in one position, will

lines of force, has been shown, by the expen

ed to fill n the narrow

passes, whether its course be over the one pole or the other So also a wire proceeding from the end of the magnet at the magnetic axis, to a point at the magnetic equator, must intersect curves equal to half those of a great plane, however small or great the length of the wire may be *though by its tortuous course it may pass* out of one plane into another on its way to the equator

3101 Further, if such a wire as that last described be revolved once round the end of the

All

pole so as at last to resume its first position, it will in the course of its journey have intersected

has no electric current induced in it. If it do not touch at the equator, still, whatever lines it intersects are twice intersected and so the same equilibrium is preserved. If the magnet rotate under the wire it acts the part of the

reason why no currents are produced, under any circumstances of motion by the application of such conducting circuits to the magnet I may

the magnet, except the very few which will remain unintersected at the equator

3103 Whilst endeavouring to establish experimentally the definite amount of the power

the results may at different times differ very much from

at the extremity of a smaller arc of declination Therefore, when quick and slow velocity were

was seen to travel on to its extreme distance

to three-fourths of that required for

though the time of revolution varied as or even in a higher degree

This effect however, was scarcely swinging deflections of 9° or 10°, produced by which were over before the needle had

together tend to form are exactly equal and

each other, whatever the position of the wire may be As the immobility of the needle is a point more easily ascertained than the extent of an arc indicated only for a moment and as the rotations of the magnet and wire conjointly can be made rapid and continuous the proof *in such cases is very satisfactory*

3107 Proceeding to experiment upon the effect of the *distance* of the wire *c Fig 11*, from the magnet the wire was made to vary so that sometimes it was not more than 8 inches long

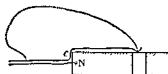


Fig 11

(being of copper and 0 04 of an inch in dia

due to ten revolutions of the magnet was observed and the average of several observations for each position of the wire taken these were very close (with the precautions before described) for the same position and the averages for different positions agreed perfectly together being 9°5 I endeavoured to repeat these experiments on distance by moving the wire and pre-

gave the same deflect on at the galvanometer whether the course of the wire was close to the magnet or far off and the deflection agreed with those obtained when the magnet was ro-

currents is determinate for the same lines of force whatever the distance of the point or plane at which their power is exerted is from the magnet Or it is the same in any two or more sections of the same lines of force whatever their form or their distance from the seat of the power may be *This is shown by the re-*

parts oppose and exactly neutralize or compensate each other

3110 In the latter case very varying sections outside of the magnet may be compared to each other thus the wire may be conceived of as

the equator may be directed so *as to intersect* the same lines of force in the contrary direction

to say be expanded in one part and compressed in another or (speaking in the language of rad ation) be more intense in one part and less intense in the other It is also as mani

in its two opposite parts an exactly equal amount of lines of force Hence the comparison of any one section of a given amount of lines of force with any other section is rendered experimentally very extensive

3111 Such results prove that under the circumstances there is no loss or destruction or evanescence or latent state of the magnetic power by distance

3112 Also that convergence or divergence of the lines of force causes no difference in their amount

3113 That obliquity of intersection causes no difference It is easy so to shape the loop

f force

rotation of the wire and magnet (3097 3100)

that when a wire is moving amongst equal lines (or in a field of equal magnetic force), and with a uniform motion, then the current of electricity produced is proportionate to the *time*, and also to the *velocity* of motion

3115 They also prove, generally, that the quantity of electricity thrown into a current is directly as the amount of curves intersected

are continuations of them, absolutely unchanged in their nature, so far as the experimental test can be applied to them Every line of force therefore, at whatever distance it may

at its exterior, or at any assumed points, to be called *poles*, or are continued and disposed of within For this purpose, let us consider the external loop (3093) of *Fig 5* When revolving with the magnet no current is produced, because the lines of force which are intersected on the one part, are again intersected in an opposing direction on the other (3110) But if one part of the loop be taken down the axis of the magnet, and the wire then pass out at the equator (3091), still the same absence of effect is produced, and yet it is evident that, external to the magnet, every part of the wire passes through lines of force, which conspire together to produce a current, for all the external lines of force are then intersected by that wire in one revolution (3101) We must therefore look to the part of the wire *within* the magnet for a power equal to that capable of being exerted externally, and we find it in that small portion which represents a radius at the central and equatorial parts When, in fact, the axial part of the wire was rotated it produced no effect (3095), when the axial, the inner radial, and the external parts were revolved together, they produced no effect, when the external wire alone was revolved, *directly*, it produced a current (3091), and when the internal radius wire alone

...ectly compensated each other (3093) This radius wire may be replaced by the magnet itself (3096, 3118)

tion in *direction* to those without, and in fact

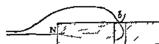


Fig 12

ed by dotted lines, the effect is the same in all the cases, both by experiment (3093) and by principle (3100) For whatever the form of the path, it will in one revolution intersect the same

tion and every other circumstance which in-

of it as represents a radius connecting together the two points at the pole or axis and at the equator, where communication with the wire is completed As was shown long ago (220), if a cylinder magnet be revolved, and the ends of the galvanometer wires *a c* be applied to the extremities of its axis, no current is evolved, but if *a* be applied to one end, it matters not which, and *c* be applied at the equator or any other part on the surface of the cylinder, a cur-

plane, and then, either a disc of copper placed there, or a wire radius only, or the magnets brought together again and these three arrangements were used in succession to complete the circuit from the axial wire (3095) to a fixed wire at the surface of the equator Whichever was employed the current produced was the same, both in direction and amount If the cylinder magnet above described (3118) be terminated at the ends by attached discs of silver or copper, the wires applied to their surfaces, as they revolve with the magnet, produce precisely the same currents as to direction as if applied to the surface of the magnet itself (218, 219)

3120 In this striking disposition of the

in closed circuits, and in their equal sum within and without No doubt, the magnet is the most heterogeneous in its nature, being composed, as we are well aware, of parts which differ much in the degree of their magnetic development, so much so that some of the internal portions appear frequently to act as keepers or submagnets to the parts which are farther from the centre, and so, for the time, to form complete circuits, or something equivalent to them, within But these make no part of the result-

when more external force is developed or it may be a portion apparently thrown inwards and so the external force diminished But in these cases, that which remains externally existent corresponds precisely to that which is the resultant internally, for when either the same, or contrary poles of a powerful horseshoe magnet were placed within an inch and a

not the slightest action at the galvanometer was perceived, the forces within the magnet and those without perfectly compensating each other

3121 The definite character of the forces of an invariable magnet, at whatever distance they are observed from the magnet, has been already insisted upon (3109) How much more

out the magnet, being exactly of the same amount! The power of a magnet may therefore be easily represented by the effects of *any* section of its lines of force, and as the currents induced by two different magnets may easily be conducted through one wire, or be, in other ways, compared to each other, so facilities may thus arise for the establishment of a standard amongst magnets

3122 On the other hand, the use of the idea

perimental arrangement, just as one desires to have a unit for rays of light or heat It does not

representing these units in any given case I have so employed them in former series of these *Researches* (2807, 2821, 2831, 2874, &c), where the direction of the *line of force* is shown at once and the relative amount of force, or of lines of

3123 The currents produced in wires when they cross lines of magnetic force, are so feeble in intensity (though abundant enough in quantity, as many results show) that a fine wire galvanometer must of necessity offer great obstruction to their passage Therefore, before en

by a single convolution of very stout wire The wire was of copper, 0 2 of an inch in diameter It passed horizontally under the lower needle, then, as nearly as might be, between that and

the upper needle, over the upper, and then [illegible]

glass cover Such a wire had abundant conduct-

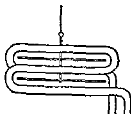


Fig 13

ing power, and though it passed but once round each needle, gave a deflection many times [illegible]

[illegible] in one loop or circuit, the passage of the wire [illegible]

[illegible] and a more perfect instrument, of the same kind, constructed, in which the conducting coil was cut out of plates of copper, so as to form a square band 0 2 of an inch in thickness, which passed twice round the vibration plane of each needle, as represented, *Fig 14.* The length of metal around the needles was 24 inches, and the galvanometer was very sensitive, but the experiments to be described were made chiefly with the former instrument

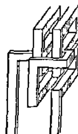


Fig 14

3124 [illegible]

indications The magnet to be used was a compound horseshoe instrument, weighing 16 lbs, and able to support 40 lbs by the keeper or submagnet It is some years since it was mag-



Fig 15

net [illegible] ly [illegible] the [illegible] ap[illegible]

wards, from their summit to the bottom or

was hardly at all affected in the time of its vibration, being adjusted so nearly astatic as to require about ten seconds to swing to the right or to the left

3125 [illegible]

locity gave the greatest result, equal at times to 140°, whilst a very slow motion gave only [illegible]

3126 On cutting the wire across, and then putting the ends together in various ways it [illegible]

cleaned and pressed closely into contact Junctions effected by soldering or dipping into cups of mercury were still better, when made with [illegible]

tions The oscillation or swing, which before was 140° or more, was now reduced to 40° On [illegible]

duced to [illegible]

bar magnets, with like ends together, passed quickly through it up to the equatorial part, [illegible]

(3124) much nearer together, the following experiments were made The distance between the poles is 1 375 inch by placing a cube of soft iron, 0 8 of an inch in the side, within this space, it was diminished to 0 575, and thus, virtually, the distance apart much lessened, and, as was afterwards shown experimentally (3130), the external power of the magnet concentrated there Then, whilst the cube was in place the thick wire of 0 2 of an inch in diameter was arranged so as to pass across the magnetic axis or place of strongest action, and fixed, after which the iron cube was alternately removed and again restored, and the effects observed Feeble electric currents were produced at these times but whether the cube was put into its place from below, or above or the sides, the current produced was always in the same direction, and when it was removed the current produced was in the reverse direction If the cube were carried up to, by, and away from, the magnetic axis in one motion, then there was no effect at the galvanometer On the other hand, when the wire was carried across the magnetic field as described (3123), so as to intersect all the lines of force in one movement, and sum up their power at the galvanometer, then there was no difference in the result, whether the iron

ternal to the magnet, was the same under both circumstances, though the distribution of it was different

3130 The very action produced by the cube, when in and out of place (3129), upon the forces which affected the stationary wire, was a proof of the difference of distribution at different times

3131 A block of bismuth, employed in place of the iron cube, had no sensible effect upon the wire whether it were still or moving

3132 This galvanometer was first employed for a repetition of all the former experiments with the bar magnets (3091, &c) The results were absolutely the same except that the amount of the deviation produced, when deviation was a result, was larger than in the former cases

3133 For the comparison of different thick-

and size such as would admit them to pass with facility over a pole of the horseshoe magnet, soldered them to the ends of two conducting rods, made of copper wire 0.2 of an inch



Fig 16

cups of the galvanometer, the parts at c are brought so close together as to touch, except for the intervention of a piece of card, and thus the parts from c to a b are thrown out of action, except as mere conductors, whilst the loop, being made to descend over one magnetic pole, intersects very nearly the whole of the magnetic curves, and always the same proportion

3134 The former magnet was too powerful

and an inch thick each, in the direction of the

either nearer to the poles, or nearer to the equator or bend, as less or more power was required The descent of the loop between the poles is then best regulated by causing the conductor wires to bear ultimately against a stopping block

3135 The effect of a quick and a slow motion was found to be the same as before (3104, 3105) Such velocities as the hand could impart were very effectual, and gave results of very considerable uniformity when quick motions were employed

or as 4, 2 and 1, their sectional areas or masses therefore were as 16, 4 and 1 Ten or twelve observations were made with each loop, the re-

Copper wire of 1/10 of an inch in thickness	16°00
Copper wire of 1/20th of an inch in thickness	44°40
Copper wire of 1/40th of an inch in thickness	57°.37

Now though the thicker wires produced the largest effect, the results were evidently not at all in proportion to the masses of the wires, the smaller having greatly the advantage in that respect On the other hand, when four of the smaller wires were placed side by side so as to form one loop equal in mass to the second loop, they gave the same result as that loop, being of the same power



Fig 17

3137 Th ...

diameters moving across them these diameters should continue to and through the galvanometer (20.), otherwise the thin wire current has an advantage given to it in the conducting part which the thick wire current has not Hence the reason why a thin wire galvanometer such as that before described (3086), gives results which are alike for thick or thin wire loops or for fasciculi of few or many wires To enlarge the comparison, I soldered on to two pairs of conductors the dimensions of those described (3133), two cylinders of copper each 5 5 inches long, but one was only 0 2 of an inch thick and the other 0 7, or twelve times the mass of the first, *Fig 17* They were then passed in succession between the poles of the magnet, and ...

for as the magnetic field was not equal in force but most intense in the magnetic axis so it is evident that whilst one part of the large cylinder in passing across was at the axis, other parts were in places of less intense force and action and so a return current may have existed in them which could not occur to the same extent in a cylinder little more than a fourth of the diameter of the former, and which at the same time ...

3138 The influence of this lateral conduction (3137), in cases of magneto-electric conduction must be well understood, otherwise in the application of the principles to investigation, errors will frequently creep in Their effect may be shown in the following instances —a loop of four wires, 0 048 of an inch in diameter (3136), was passed over the pole of the magnet and produced a certain result of deflection or swing when the wires were separated two and two, so as to be half or three-quarters of an inch apart, and when, therefore, in moving across the magnetic field, one pair went before the others the effect was less, for the reason ...

3139 A loop was constructed of seventy six ...

smaller numbers of wires one with the other, that is of most value I will give the averages of each number for several observations in the reverse order in which they were obtained and I introduce the results with larger numbers of wires only for the general purpose of showing how the effect passes into that with the cylinder of copper (3137) the galvanometer conductors always being of the same length and thickness

1 wire produced an average swing of	8° 3
2 wires produced an average swing of	15° 3
3 wires produced an average swing of	21° 8
4 wires produced an average swing of	27° 9
5 wires produced an average swing of	31° 4
6 wires produced an average swing of	37° 8
8 wires produced an average swing of	50° 1
12 wires produced an average swing of	65° 1
... average swing of	80° 5

66 a little stronger
76 stronger swung the needle freely round the circle

Each time that the needle passed 180°, it was returned that the torsion force might remain the same for every case

3140 When the loop of four equal (3136) was employed, so arranged ...

spect to the part which passed between the

axis or parallel to it, i e, whether the wires in moving formed a band which moved edgeways or flatways, the results were the same as with the four wires close together, so as to represent, as far as they could, a round or square wire.

3141 From all these results it may be concluded that the current or amount of electrici-

the line of force, which has relation to the *polarity of the* power, *nor by that width or dimension* of it which includes the number or *amount* of the lines of force, and which, corresponding to the direction of the motion, has relation to the *equatorial* condition of the lines, but is jointly as the compound ratio of the two, or as the mass of the moving wire The power acts *just as well on the interior portions of the* wire as on the exterior or superficial portions, and a central particle, surrounded on all sides by copper, is just in the same relation to the force as those which, being superficial, have air next them on one side

alcohol and oil of turpentine The experiments in air were repeated between those with the liquids so as to give a very consistent and safe result as to the equality of action in all the cases

3143 The effect of *variation of substance* was the next subject which seemed to me important to bring under investigation, because it has a direct relation to the amount of force exerted, or ready to be exerted, within solid bodies, at any distance from the magnet, in situations and under circumstances where it was absolute-

3144 In an early series of these *Researches*[1] experiments bearing upon this subject are described (205–213) Wires of different metals were moved across the lines of force of a magnet, and the result arrived at was that the currents induced in these different bodies were proportional to their electro-conduction power (202, 213)

3145 The thick wire galvanometer (3123),

copper wire (3133) were prepared with wires of different metals, all of the same diameter namely, 0 04 of an inch, being only 1/45th of the substance of the conducting and galvanometer wire The metals were copper, silver, iron tin

ing part of the system is very good and remains the same The results with these loops were as follows, being the average of from six to ten experiments for each loop

Copper	63° 0	Iron	18° 0
Silver	61° 9	Platinum	16° 9
Zinc	31° 5	Lead	12° 1
Tin	19° 1		

might exist between paramagnetic and diamagnetic metals, three metals were selected, namely, tin, iron and lead in wires, as before,

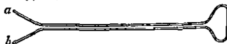


Fig 18

of 0 04 of an inch diameter, but the length was restricted to 3 inches, instead of extending to

peculiar difference existing between iron on the one hand and tin and lead on the other be

3147 The many experiments made with each metal were very close together The average of the results for the three metals was as follows

Tin	37°1
Iron	34°.8
Lead	25°4

The proportions and therefore the results are almost identical with those obtained before (3145

3148 When lead and copper arranged at the bar magnets (3084 3085) had been compared in former experiments with each other by the fine wire galvanometer the results for both had been the

e u e imited in the product on of their peculiar action by those circumstances of mass already described (3137) To show that that was the case I now with the thick wire galvanometer employed two equal loops of copper and iron wire 0 ? of an inch in th ckness *Fig 16* (3133) passing them equably over the pole of the small horseshoe magnet reduced by the keeper (3134) The results were very consistent, and the mean of them was for

Copper	41°7
Iron	33°7

3149

omparatively to carry on to the galvanometer nearly all the effect of the excitement it was as great as 1 to 3 5 the difference being in the latter case above tenfold what it was in the former

3150

wires so as to be in all respect like that of copper before described (3137) In this case the iron not only rose up to the copper in effect but even surpassed it the results being for coppe

35°66 and for iron 38°.32 Thus under these circumstances of mass the difference between

a similar cylinder of bismuth to conductors Its effect with the same magnet and force was 23°

3152 So the current of electric ty exc ted in different substances moving across lines of

netic force

3154 Such a conclus on as that just arrived at brings on the question of what is *magnetic*

d red nto the c rcu t it re-

polarity, and how is it to be defined? For my own part, I should understand the term to mean the opposite and antithetical actions

of the earth, or a part of it, may again be referred to as the natural case, and a free needle

artificial source as the electro magnetic helix,

not to hypotheses only, beyond that included in the above description, I am not aware that it has ever been distinctly and clearly expressed It may be so for I dare not venture to say that I recollect all I have read, or even all the con-

by attractions and repulsions, i e , by such like mutual actions of particular bodies on each other under the magnetic influence? A weak solution of protosulphate of iron, if surrounded

is true with stronger cases We cannot doubt it would be true even up to iron, nickel, and cobalt, if we could render these bodies fluid in

stronger or weaker at pleasure But in the case of the solutions, we cannot suppose that the weaker has one polarity in the stronger solution and another in the water The lines of force

pulsions

3156 Here, therefore, we have a *difference* in the two modes of experimental indication not

interpret them correctly To assume that pointing is always the direct effect of attractive and

vancement of truth and a defence of wrong assumptions and error

3157 What is the idea of polarity in a field of *equal force* (whether it be occupied by air or by a mass of soft iron)? A magnetic needle, or an oblong piece of iron, would not show it in the air or elsewhere, except by disturbing the

might exist, which, when in its stable position,

needle cannot show polarity in a field of equal

as we comprehend or understand distinct when thinking of magnetic needles At least such at present appears to me to be the case, from the consideration of the action of thin and thick wires (3141) and wires of different substances (3153)

3159 As an experimentalist, I feel bound to let experiment guide me into any train of thought which it may justify, being satisfied that experiment, like analysis, must lead to

[1] One could easily imagine hypothetically a needle that should do so

of natural power In order to extend its indications and vary the form in which the principle of the moving wire may be applied I had an apparatus constructed, Fig 19, consisting of a wooden axis, one extremity of which was ter-

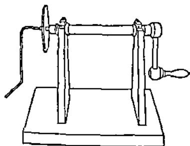


Fig 19

minated by a copper screw, intended to receive and carry one or more discs of metal that might be ...

as to bear into and against the surface of a cup-shaped cavity at the end of the axial screw and the other was applied by the hand, or so fixed as to bear by a ...

... Discs of metal were prepared for this apparatus each 2 5 inches in diameter and of different thicknesses and material When a disc of copper was fixed on the axis, and adjusted in association with the large horseshoe magnet (3159), as described above three or even two revolutions of it would deflect the needle of the ...

greatest velocity, consequently moves through more space and that in a part where the lines of force are *most concentrated*

3161 The contact at the end of the axle should always be carefully watched and made good The degree of pressure on the edge *of the* disc should not be too slight otherwise the contact under the circumstances of the motion is not sufficient to carry forward the same con-

friction of copper wire against the copper disc there is very little evolution of current When the copper wire presses against the edge of an iron disc there is far more In either case however, the effect may be eliminated or compensated for, in whichever direction the disc is re-

maximum effect but even surpassed (3137) Then an *iron* disc of 0 05 in thickness was placed on the axle and gave as its mean result

arated from mutual contact in respect to their

revolutions, gave an average de

and when the iron disc was in the circuit the deviation produced by it was 11° 91 Here therefore the proportions were nearly the same when the two discs were subject at the same moment to the magnetic power as when they were examined separately Both have fallen a little but not in any manner which seems to indicate that the iron has had any peculiar influence in altering or affecting the lines of force passing across the magnetic field The effect which has taken place appears to be one due to the action of the collateral mass of conducting matter

3164 If the direction of the electric current induced by the magnetic force in the moving metal be taken as the true indication of polarity and I think it cannot be denied that it represents that character of the force which the term polarity is intended to express and is unchangeably associated with that character then these results show that the polarity of the lines of force within the iron is the same with that

muth (2431 3151 3168) and numerous other phenomena the same conclusion may be drawn as to the lines of force within that substance for the effects are the same with regard to the production of a current in it and so further evidence is added to that which I have given tending to show that bismuth is not polarized in the reverse direction as iron or a magnet (2429 2640) By reference to the phenomena presented by the relative actions of paramagnetic and diamagnetic substances the same conclusions may be drawn with respect to all bodies and to space itself (2787 &c)

3165 That the iron disc affects the disposition of the *lines of force* is no doubt true and the extent to which this is done is easily seen by fixing a small magnetic needle about 0 1 or 0 05 of an inch in length across the middle of a piece of stretched thread as an axis and then

through the air close to the iron is exactly equal in amount of force to a section taken across parallel to and through the iron disc (3163) All iron under induction must have just

and the same is true as it appears to me of any other paramagnetic or diamagnetic substance whatever The same is true *for the magnet itself* for a section through the magnet has been shown to be exactly equal to a section anywhere through the outer lines of force (3121) and

ity and every other point

3166 I have used the phrase *conduction polarity* on a former occasion (2818 2835) but so limited that it could lead to no mistake of my meaning either then or now It requires no

perfect no doubt but as general as could be made under the circumstances When this disc was rotated in the one direction it gave a deflection in the same direction as if a copper or iron disc had been used when rotated the

tween the magnetic poles, as they are through copper and iron The induced current is small, both here ...

by those parts of the disc, which, not being in the place of greatest action, are conducting back those currents formed by the radial parts in the place of maximum effect, I had a wooden disc constructed, 0 2 in thickness and 2 5 inches in diameter, the centre of which was copper, for the purpose of attachment and electrical connexion, and the outer edge a ring of copper not more than 1/40th of an inch in thickness The two were ...

... than the 1/140th part of the full copper disc and this indicates how much of the electricity put in motion there by the magnetic force must be returned back in short circuits in the other parts of the disc

3170 The disc apparatus shows well the dependence of the induced current upon the intersection of the lines of force (3082, 3113) If the disc b...

... rev... net... the galvanometer

3171 The relation of the induced current to the electro-conducting power of the substance, amongst the metals (3152) leads to the presumpt...

... result.

3172 All the results described are those obtained with moving metals But mere motion would not generate a relation, which had not a foundation in the existence of some previous state, and therefore the quiescent metals must be in some relation to the active centre of force, and that not necessarily dependent on their paramagnetic or diamagnetic condition be cause a metal at zero in that respect would have an electric current generated in it as well as the others The relation is not as the attractions or repulsions of the metals, and therefore not magnetic in the common sense of the word, but according to some other function of the power Iron, copper, and bismuth are very different in the former sense, but when moving across the lines of force give the same general result, modified only by electro-conducting power

3173 If such a condition be hereafter verified ...

magnetic power

3174 On bringing this paper to a close, I cannot refrain from again expressing my conviction of the truthfulness of the representation, which the idea of lines of force affords in regard to magnetic action All the points which are experimentally established with regard to that action, i e , all that is not hypothetical, appear to be well and truly represented by it Whatever idea we employ to represent the power ...

customed, indeed, to employ them, and espe-

have always endeavoured to make experiment the test and controller of theory and opinion, but neither by that nor by close cross examination in principle have I been made aware of any error involved in their use

3175 Whilst writing this paper I perceive, that in the late series of these *Researches* Nos XXV, XXVI XXVII, I have sometimes used the term *lines of force* so vaguely as to leave the reader doubtful whether I intended it as a merely representative idea of the forces, or as the description of the path along which the power was continuously exerted What I have said in the beginning of this paper (3075) will render that matter clear I have as yet found no reason to wish any part of those papers altered except these doubtful expressions but that will be rectified if it be understood that, wherever the expression *line of force* is taken simply to represent the disposition of the forces, it shall have the fullness of that meaning, but that wherever it may seem to represent the idea of the *physical mode* of transmission of the force, it expresses in that respect the opinion to which I incline at present The opinion may be erroneous, and yet *all* that relates or refers to the disposition of the force will remain the same

3176 The value of the moving wire or conductor, as an examiner of the magnetic forces, appears to me very great, because it touches the physics of the subject in a manner altogether different to the magnetic needle It not only gives its indications upon a different principle and in a different manner, but in the mutual action of it and the source of power, it affects the power differently The wire when quiescent does not sensibly disturb the arrangement of the force in the magnetic field, the needle when present does When the wire is moving it does

these advantageous points, the principle is available within magnets, and paramagnetic and diamagnetic bodies, so as to have an application beyond that of the needle, and thus give experimental evidence of a nature not otherwise attainable

Royal Institution, October 9, 1851

TWENTY-NINTH SERIES[1]

§ 35 *On the Employment of the Induced Magneto electric Current as a Test and Measure of Magnetic Forces*

RECEIVED DECEMBER 31, 1851, READ MARCH 25 AND APRIL 1, 1852

3177 THE proposition which I have made to

tice necessary for such a purpose, and especially that I should prove that the amount of current induced is precisely proportionate to the amount of lines of magnetic force intersected

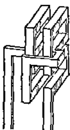
The proof already given is, I think, sufficient

for those who may repeat the experiments, but in order to accumulate evidence, as is indeed but proper in the first announcement of such a proposition, I proceeded to experiment with the magnetic power of the earth, which presents us with a field of action, not rapidly varying in force with the distance, as in the case of small magnets, but one which for a given place may be considered as uniform in power and direction, for if a room be cleared of all common

... power Now the force being the same everywhere, the proportion of it to the current evolved in the moving wire is then perhaps more simply and directly determined, than in the case where, a small magnet being employed, the force rapidly changes in amount with the distance

¶ i *Galvanometer*

3178 For such experimental results as I now propose to give, I must refer to the galvanometer employed and the precautions requisite for its proper use The instrument has been already described in principle (3123), and a figure of the conductor which surrounds the needles given This conductor may be considered as a square copper bar, 0 2 of an inch in thickness, which passes twice round the plane of vibration of each of the needles forming the astatic combination, and then is continued outwards and terminates in two descending portions which are intended to dip into cups of mercury As both the needles are within the convolutions of this bar, an indicating bristle or fine wire of copper is fixed parallel to, and above them upon the same axis, and this, in travelling over the usual graduated circle, shows the *place and the extent of* vibration or swing of the needles below The suspension is by cocoon silk, and in other respects the instrument is like a good ordinary galvanometer


Fig 1

3179 *It is highly important* that the bar of copper about the needles should be *perfectly* clean The vertical zero plane should, according to the construction, be midway between the two vertical coils of the bar, *Fig 1*, instead of which the needle at first pointed to the one side or the other, being evidently attracted by the upright portions of the bar I at first feared that the copper was magnetic, but on cleaning the surface carefully with fine sandpaper, I was able to remove this effect, due no doubt to iron communicated by handling or the use of tools, and the needle then stood truly in a plane equidistant from the two coils, when that plane corresponded with the magnetic meridian

3180 The connections for this galvanometer (3123, 3133) were all of copper rod or wire 0 2 of an inch in diameter, but even with wires of this thickness the extent of the conductors should not be made more than is necessary, for the increase from 6 to 8, 10 or 12 feet in length, makes a considerable difference at the galva-

...

found it very convenient and certain to tin and amalgamate the ends of the conductors wiping off the excess of mercury The surfaces thus prepared are always ready for a good and perfect contact

3181 When the needle has taken up its posi-

...

and quite insensible to the eye ...

earth's force), is not equal on the two sides, the consequence is *that the extent of*

the two directions is not equal for equal pow

suspending filament Also there may be other causes as the presence about a room in its walls and other places of unknown masses of iron wh ch may render the forces on opposite sides of the instrument *zero unequal in a slight de* gree for these reasons it is better to make *double observations* All the phenomena we have

fore always in measuring the power of a pole or the effect of a revolving intersecting wire made many observations in both directions e ther alternately or irregularly have then ascertained the average of those on the one s de and also on the other (which haved ffered in dif ferent cases from 1/60th to 1/500th part) and have then taken the mean of these averages as the expression of the power of the induced electric current or of the magnetic forces inducing it

3183 Care must be taken as to the pos tion of the instrument and apparatus connected *with it in relation to a fire or sources of different* temperatures that parts wh ch can generate thermocurrents may not become warmed or cooled n d fferent degrees The instrument

moments d sturbed the ind cations and ren dered them useless for some time

measurer the following trials were made A loop like that before described (3133) *Fig 2*



Fg 2

was connected with the galvanometer by com mun cations which removed the loop 9 feet from the instrument and it was then fixed A compound bar magnet consisting of two plates each 12 inches long 1 inch broad and 0 5 in

wards through the loop until the latter coinci ded with the equator of the magnet (3191) after which it could be quickly removed and the *same operation be repeated at pleasure* When the magnet was tl us moved the loop be ng un connected (at one of the mercury cups) with the galvanometer there was no sensible change of place in the needles the direct influence of the magnet at this distance of 9 feet being too small for such an effect

3185 It must be well understood that in all the observations made with this instrument the *swing* is observed as the effect produced unless otherwise expressed A constant current in an instrument will give a constant and con tinued deflection but such is not the case here The currents observed are for short periods and they give as it were a blow or push to the needle the effect of wh ch in swinging the needle continues to increase the extent of the deflection long after the current is over Nevertheless tl e extent of the swing is depend ent on the electricity wh ch passed in that br ef current and as tl e experiments seem to ind cate is simply proportional to it whether the

time of its continuance

3186 The compound bar being introd ced

brought to zero and the bar removed which

should be remembered that a swing of the

cating wire out of the mercury remove the magnet which by th s motion does noth ng restore the mercury contact and re ntroduce the magnet into the loop before a tenth part of the time has passed during which the needles

urged by the first impulse, would swing In this way two impulses could be added together, and their joint effect on the needle observed, and, indeed, by practice, three and even four impulses could be given within the needful time, i e within one-half or two-thirds of the time of the full swing, but of course the latter impulses would have less power upon the needles, because these would be more or less oblique to

[illegible]

every introduction of the same magnet

3187 Proceeding in this way I obtained results for one, two, three, and even four introductions with the same magnet

One introduction	15°
Two introductions	31° 25
Three introductions	46° 87
Four introductions	58° 50

Here the approximation to 1, 2, 3, 4 cannot es-

[illegible]

where only one half or one third of it is add[illegible] to a half or a third of the whole result Thus, if we halve the arc for two introductions of the pole, it gives 15° 625 if we take the third of

[illegible]

the fourth, which is 14° 625, is less

[illegible]

One introduction	8°
Two introductions	15° 75
Three introductions	23° 87
Four introductions	31° 66

which numbers are very closely as 1, 2, 3 and 4 If we divide as before, we have 8°, 7°.87, 7° 95, 7° 91, so that if only 0 09 be subtracted from the first observation, or 8°, it leaves that simple result [2]

[illegible]

for small arcs nearly proportional to the magnetic force which has been brought into action on the moving wire [3]

[1] *See* [also] note to (3189)

$\sin \frac{15}{2}$	$= \sin 7° 30'$	$= 130526$		130526
$\sin \frac{31\ 25}{2} = \sin 15\ 625$	$= \sin 15° 37\ 5$	$= 269200$	$\frac{269200}{2}$	$= 134600$
$\sin \frac{46\ 87}{2} = \sin 23\ 435$	$= \sin 23° 26\ 1$	$= 3976818$	$\frac{3976818}{3}$	$= 1328606$
$\sin \frac{58\ 50}{2} = \sin 29\ 25$	$= \sin 27° 15$	$= 4886212$	$\frac{4886212}{4}$	$= 1221553$
$\sin \frac{8}{2}$	$= \sin 4°$	$= 0697565$		0697565
$\sin \frac{15\ 75}{2} = \sin 7° 875$	$= \sin 7° 52\ 5$	$= 1370123$	$\frac{1370123}{2}$	$= 0685061$
$\sin \frac{23\ 87}{2} = \sin 11° 935$	$= \sin 11° 56\ 1$	$= 2068019$	$\frac{2068019}{3}$	$= 0689340$
$\sin \frac{31\ 66}{2} = \sin 15° 83$	$= \sin 15° 49\ 8$	$= 2727840$	$\frac{2727840}{4}$	$= 0681960$

[2] Mr Christie has recalled my attention to a paper in the *Philosophical Transactions* 1833 p 95 in [illegible] 111 &c the effect

[3] The error does not interfere with the general reason-

3190 I have found the needles very constant

in comparative experiments Those which I

3191 With this instrument thus examined I repeated most of the experiments with loops formerly described (3133 &c) with the same results as before It was also ascertained that the equator of a regular bar magnet was the place at which the loop should be arrested to produce the maximum action and that if it came short of or passed beyond that place the final result was less Employing a magnet 12 inches long when the loop passed

?3 inches over the pole the deflection was 5° 91
4 1 inches over the pole the deflection was 7° 50
5 1 inches over the pole the deflection was 7° 74
6.1 inches over the pole the deflect on was 8° 16
8 0 inches over the pole the deflection was 7° 75
9 0 inches over the pole the deflect on was 6° 50

¶ ii *Revolving Rectangles and Rings*[1]

3192 The form of moving wire which I have adopted for experiments with the magnetic forces of the earth (3177) is either that of a rectangle or a ring If a wire rectangle (*Fig 3*) be placed in a plane perpendicular to the dip and then turned once round the axis a b the two parts c d and e f will twice intersect the lines of magnetic force within the area c e d f In the first 180° of revolution the contrary direction in which the two parts c d and e f intersect those lines will cause them to conspire in

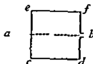


Fig 3

— — + on

[1] A friend has po nted out to me that in July 1832 Nob l made experiments with rotat ng rings or spirals subject to the earth s magnet c influence they

be open at b and the ends there produced be

gathered up and sent on to the galvanometer to be measured The parts c e and d f of the rectangle may be looked upon simply as conductors for as they do not in their motion intersect any of the lines of force so they do not tend to produce any current

3193 The apparatus which carries these rectangles and is also the commutator for changing the induced currents consists of two up-

other projects and is shaped as in *Fig 4* It

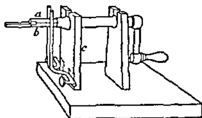


Fig 4

may there be seen that two semicylindrical

part of the upright c terminating there in sockets with screws for the purpose of receiving the

perfectly straight press strongly against the

tween the commutator plates arrive at and pass the horizontal plane their contact with these bearing ro ls is changed and consequently the direction of the current proceeding from these plates to the rods and so on to the galvanometer is changed also The other or outer ends of the commutator plates are tinned for the purpose of being connected by soldering to the ends of any rectangle or ring which is to be subjected to experiment

3104 ...

mutator plates, so that it shall revolve with the axle A small copper rod forms a continuation of that part of the frame which occupies the place of axle, and the end of this rod enters in to a hole in a separate upright, serving to support and steady the rectangle and its frame The frames are of two or three sizes so as to receive rectangles of 12 inches in the side, or even larger, up to 36 inches square The rectangle is adjusted in its place, so that it shall be in the horizontal plane when the division between the commutator plates is in the same plane, and then its extremities are soldered to the two commutator plates, one to each It is now evident that when dealing with the lines of force of the earth, or any other lines, the axle has only to be turned until the upright copper rods touch on each side at the separation of the commutator plates, and then the instrument adjusted in position, so that the plane of the ring or rectangle is perpendicular to the direction of the lines of force which are to be examined, and then any revolution of the commutator and intersecting wire will produce the maximum current which such wire and such magnetic force can produce The lines of terrestrial magnetic force are inclined at an angle of 69° to the horizontal plane As, however, only comparative results were required, the ...

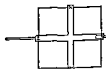


Fig 5

cause of error or variation was introduced into the results As no extra magnet was employed, the commutator was placed within 3 feet of the galvanometer, so that two pieces of copper

and a rectangle or other formed loop to be employed with the lines of terrestrial force In the ...

loop of two or more convolutions and yet pass over the pole, then twice or many times the electricity will be evolved than a single loop can produce (36) In the case of the earth s force, the contrary result is true for as in circles, squares, similar rectangles, &c , the areas inclosed are as the squares of the periphery, and the lines of force intersected are as the areas it is much better to arrange a given wire in one simple circuit than in two or more convolutions Twelve feet of wire in one square intersects in one revolution the lines of force passing through an area of nine square feet, whilst if arranged in a triple circuit, about a square of one foot area, it will only intersect the lines due to that area and it is thrice as advantageous to intersect the lines within nine square feet once, as it is to intersect those of one square foot three times

3196 A square was prepared, containing 4 feet in length of copper wire 0 05 of an inch in diameter, it inclosed one square foot of area, ...

force by this rectangle, observations were made on both sides of zero as already recommended (3182) Nine moderately quick direct revolutions (i e, as the hands of the clock) gave as the average of many experiments 23° 87 and nine reverse revolutions gave 23° 37 the mean of these is 23° 62 for the nine revolutions of the rectangle and therefore 2° 624 per revolution Now the six quick revolutions (3196) gave 15° 66 which is 2° 61 per revolution, and the twelve quick revolutions gave 31° 33, which is also 2° 61 per revolution and these results of 2° 624 2° 61, and 2° 61 are very much in accordance and give great confidence in this method of investigating magnetic forces [1]

3198 A rectangle was prepared of the same length (4 feet) of the same wire but the sides were respectively 8 and 16 inches (*Fig 6*), so


Fig 6


Fig 7

that when revolving the intersecting parts should be only 8 inches in length instead of 12 The area of the rectangle was necessarily 128 square inches instead of 144 This rectangle showed the same difference of quick and slow rotations as before (3196) When nine direct revolutions were made the result was 20° 87 swing Nine reverse revolutions gave an average of 20° 25 swing the mean is 20° 56 or 2° 284 per revolution A third rectangle was prepared of the same length and kind of wire the sides

21° 06 or 2° 34 per revolution

3199 Now 2° 34 is so near to 2° 284 that they may in the present state of the investigation be considered the same The little differ-

have had no influence in altering the result

is still further shown by comparing the results with those obtained with the square The area in that case was 144 square inches and the effect per revolution 2° 61 With the long rectangles the area is 128 square inches and the mean of the two results is 2° 312 per revolution Now 144 square inches is to 128 square inches as 2° 61 is to 2° 32 a result so near to 2° 312 that it may be here considered as the same proving that the electric current induced is directly as the lines of magnetic force intersected by the moving wire [2]

3200 It may also be perceived that no difference is produced when the lines of force are chiefly disposed in the direction of the motion of the wire or else chiefly in the direction of the length of the wire i e, no alterations are occasioned by variations in the *velocity* of the motion or of the length of the wire provided the amount of lines of magnetic force intersected remains the same

[1]
$$\sin\frac{15\ 66}{2} = \sin\ 7°\ 83 = \sin\ 7°\ 49\ 8 = 1362343 \qquad \frac{1362343}{6} = 0227057$$
$$\sin\frac{23\ 62}{2} = \sin\ 11°\ 81 = \sin\ 11°\ 48\ 6 = 2047069 \qquad \frac{2047069}{9} = 0227474$$
$$\sin\frac{31\ 33}{2} = \sin\ 15°\ 665 = \sin\ 15°\ 40 = 2700403 \qquad \frac{2700403}{12} = 0225034$$

[2] Oblong rectangles of 128 square inches area give a mean of 20° 81 (3198) The rectangle of 144 square inches gave a mean of 23° 62 (3197)
$$\sin\frac{20\ 81}{2} = \sin\ 10°\ 405 = \sin\ 10°\ 24\ 3 = 1806049$$
$$\sin\frac{23\ 62}{2} = \sin\ 11°\ 81 = \sin\ 11°\ 48\ 6 = 2047069$$
$$\frac{128}{144} = \frac{8}{9} \qquad 1806049 \times 9 = 1\ 6254441 \qquad 2047069 \times 8 = 1\ 6376552$$
Or thus
$$\frac{1806049}{8} = 0225756 \qquad \frac{2047069}{9} = 0227452$$

3201 Having a square on the frame 12 inches in the side but consisting of copper wire 0 1 of an inch in thickness, I obtained the average result of many observations for one, two, three, four and five revolutions of the wire

One revolution gave 7° equal to 7° per revolution

These results are exceedingly close upon each other, especially for the first 30°, and confirm several of the conclusions before drawn (3189, 3199) as to the indications of the instrument, the amount of the curves, &c [1]

3202 At another time I compared the effect of equable revolutions with other revolutions very irregular in their rates, the motion being sometimes even backwards and continually differing in degree by fits and starts, yet always so that within the proper time a certain number of revolutions should have been completed The rectangle was of wire 0 2 of an inch thick the mean of many experiments, which were closely alike in their results, gave for two smooth, equable revolutions, 17° 5, and also for two irregular uncertain revolutions the same amount of 17° 5

3203 The relation of the current produced to the mass of the wire was then examined a relation, which has been investigated on a former occasion by loops and small magnets (3133) [2] For the present purpose two other equal squares were prepared, each a foot in the side, but the copper wire of which they consisted was respectively 0 1 and 0 2 of an inch in diameter, so that with the former rectangle they

employed, six direct revolutions gave an average result of 41° 75, and six to the left gave 46° 25 the mean of the two is 44°, and this divided by six gives 7° 33 as the deflection per revolution Again, three direct revolutions gave 20° 12, and three reverse revolutions 23° 1, the mean being 21° 61, and the deflection per revolution 7° 20 This is very close to the former

accord with a ratio in the present case of 2° 61 to 7° 26, and it is as 2° 61 to 7° 242, almost identical

3204 The average of the direct and reverse revolutions is seen above to differ considerably, i e, up to 4° and 5° in the higher case This

large swings that I employed only a small number of revolutions Three direct revolutions gave an average of 25° 58 three reverse revolutions gave an average of 25° 58, three reverse revolutions gave 28° 5, the mean is 27° 04 and

		Differences.		
				0610485
[1] $\sin\frac{7}{2} = \sin$ 3° 30	= 0610485	050"331		
$\sin\frac{13\ 875}{2} = \sin$ 6° 9375 = sin 6° 56 25	= 1207866	0620924	$\frac{1207866}{2}$	= 0603933
$\sin\frac{21\ 075}{2} = \sin$ 10° 5375 = sin 10° 32 25	= 1828790	0644329	$\frac{1828790}{3}$	= 0609596
$\sin\frac{28\ 637}{2} = \sin$ 14° 3185 = sin 14° 19 11	= 2473119	0752595	$\frac{2473119}{4}$	= 0618279
$\sin\frac{37\ 637}{2} = \sin$ 18° 8185 = sin 18° 49 11	= 3225714		$\frac{3225714}{5}$	= 0645142

[2] See a corresponding investigation by Christie *Philosophical Transactions* 1833 p. 120

the amount per revolution 9° 01 Again, two direct revolutions gave 17° 5, two reverse revolutions gave 18°, the mean is 17°.75, and the amount per revolution 8° 87, the mean of the two final results is 8° 94, and is again an increase on the effect produced by the preceding rectangle of wire, only half the diameter of the present This thickness of wire was also employed formerly as a loop (3136), and if we compare the results then obtained with the present results, it is remarkable how near th[illegible] to each other a[illegible] great[illegible] [illegible] were [illegible], the currents indicated by t[illegible] galvanometer were as 1 00, 2 77, and 3 58, now that they are employed as rectangles subject to the earth's magnetic power, they are as *1 00, 2 78, and 3 45*[1]

3206 I formed a square, 12 inches in the side, of four convolutions of copper wire 0 05 of an inch in diameter, the single wire which formed it was consequently 16 feet long Such a rectangle will, in revolving, intersect the same number of lines of magnetic force as the former rectangle made with wire 0 1 in diameter (3203) there will also be the same mass of wire intersecting the lines, but, as a conductor, the first wire has in respect of diameter, only one-fourth the conducting power of the second, and then, to increase the obstruction, it is four times as long Six direct revolutions gave an average result of 20° 6, and six reverse revolutions 19° 7, the mean is 20° 15, and the proportion per revolution 3° 36 With the other rectangle having equal area and mass, but a single wire (3203), the result per revolution was 7° 26, being above, though near upon twice as much as in the present case Hence for such an excellent conducting galvanometer as that described (3123, 3178), the moving wire had better be as one single thick wire rather than as many convolutions of a thin one. If it be, under all variations of circumstances, the same wire for the same area, then, of course, two or more convolutions are better than one

[1] $\sin\frac{27\ 04}{2} = \sin\ 13° 52 = \sin\ 13°\ 31\ 2 = 2337848$ $\frac{2337848}{2} = 0779283$ The square 12 inches side of wire 0 05 in diameter gave for six revolutions (3196 3197) .0227057 as sin ½ A for one revolution A like square of wire 0 10 in diameter gave for five revolutions (3021) $\frac{3225714}{2} = 06451428$ as sin ½ A for one revolution A like square of wire 0 20 in diameter gave 0779283 as sin ½ A for one revolution

$\frac{06451428}{.0227057} = 2\ 841$ $\frac{0779293}{0227057} = 3\ 432$

3207. It was to be expected, however, that the thin wire rectangle would produce a current of more *intensity* than that in the thick wire, though less in quantity, and to prove this point experimentally, I connected the two rectangles *in succession with Rhumkorff's* galvanometer (3086), having wire only 1-135th of an inch in diameter That of the single thick wire *now gave only 1° 66 of swing for twelve revolutions* of the rectangle, or 0° 138 per revolution, whilst the other of four convolutions of thin wire gave for twelve revolutions 7° 33, or 0° 61 per revolution Now the needles of the two instruments were not very different in weight and other circumstances, so that without pretending to an accurate comparison, we may still perceive an immense falling-off in both cases, due to the obstruction of the fine wire in the Rhumkorff's galvanometer for the thick *wire it is from 7° 26 to 0°.138, and for the thin* wire from 3° 36 to 0° 610 Still the thin wire rectangle has lost far less proportionately in power than the other, and by this galvanometer is above four times greater in effect than the rectangle of thicker wire Of the thick wire effect less than a *fiftieth* passes the fine wire galvanometer, all the rest is stopped of the fine wire effect more than ten times this proportion, or between a fourth and a fifth (because of the higher intensity of the current), surmounts the obstruction presented by the instrument The quantity of electricity which really passes through the fine wire galvanometer is of course *far less than in the proportion indicated above* The thick wire coil makes at the utmost four convolutions about the needles, whereas in the fine wire coil there are probably *four hundred* or more, so that the electricity which really travels forward as a current, is probably not a hundredth part of that which would be required to give an equal deflection in the thick wire galvanometer Such a circumstance does not disturb the considerations with respect to the relative intensity of the magneto-electric currents from the two rectangles, which have been stated above

3208 A large square was now constructed of copper wire 0° 2 of an inch in diameter The square was 36 inches in the side, and therefore consisted of 12 feet of wire, and inclosed an area *of 9 square feet it was attached to the* commutator by expedients, which, though sufficient for the present, were not accurate in the adjustments *It produced a fine effect upon the* thick wire galvanometer (3178), for one revolution caused a swing deflection of 80° or more,

and when its rotation was continuous the needles were permanently deflected 40° or 50° It was very interesting to see how when this rectangle commenced its motion from the horizontal plane the current increased in its intensity and then diminished again the needles showing that whilst the first 10° or 20° of revolution were being passed there was very little power exerted on them but that when it was

pulses (3192) given in one revolution of the rectangle Being large and massive in proportion to the former wires more time was re-

han this was easy convenient and quick

measurement of one rotation having an easy quick velocity The average of fifteen observations to the right which came very near to each other was 78° 846 the average of seventeen similar observations to the left was 78° 382 and

between the intersecting portions of wire it was rather less than 36 inches having therefore corrected this error I repeated the obser- ... of 81° 44 The

making it more accurate

it is to me an evidence of the sensibility and certainty of the instrument

3210 As the two impulses upon the needles in one revolution (3208) are here sensibly apart in time and as the needle has as evidently and ... the second

subtract it from 81° 44 it gives 40° 07 as the value of the second impulse under the changed place of the needle This difference of the two impulses of one revolution namely 41° 37 and 40° 07 is in perfect accordance with the results that were to be expected

3211 The square of this same copper wire 0 2 in thickness employed on a former occasion

per revolution If in comparing these cases we take the ninth part of 81° 44 it gives 9° 04 a number so near the former that we may consider the two rectangles as proving the same result and at the same time the truth of the statement that the magneto-electric current evolved is as the amount of lines of force intersected A ninth part of the result with the large rectangle (78° 614) before its area was corrected is 8° 734 so that the one is above and the other below the amount of the 12-inch rec

the areas [1]

3212 The moving wire in place of being

[1] The 9 square feet rectangle gave 81° 44 sin $\frac{81\ 44}{2}$ = sin 40 7? = sin 40° 43 2 = 6573630 or taking 41° 37 for the half revolution for $\frac{1}{2}$ A (3210) s n 41° 37 = sin 41° 22 ? = 6609190 which divided by nine give 073435 as the force per square foot. The 1 square foot rectangle of like wire (3205) gave 07714 or 07793 as the force of one revolution the first of which s 00370 more than $\frac{1}{9}$ of the measure of the effect of the large square the difference being about $\frac{1}{23}$ of 07714 or the whole force of one revolution

thickness was employed with the earth's magnetic force as before, it gave as the average of six revolutions many times repeated 5° 995, or 0° 999 per revolution For twelve revolutions it gave a mean of 12°.375 or 1° 031 per revolution,[1] the mean of the two results with such different numbers of revolutions being 1° Another ring, consisting of 26 convolutions of copper wire 0 04 of an inch in diameter, was constructed and had a mean diameter of 3 6 or 3 7 inches, it contained 300 inches in length of wire So the masses of the metal in the two rings are nearly the same, but the latter wire is singly only 1 25th of the mass of the former It gave for twelve revolutions a mean of 6° 25, or 0° 52 per revolution With the earth's power and the thick wire galvanometer, it gave therefore little more than half the result of the single thick wire ring We know from former considerations (3206), that if the 300 inches had been made into one single ring, it would have given a very high effect compared to the present

3213 The application of the principle of the moving wire in the form of a revolving rectangle, makes the investigation of *conducting* power, and the results produced by difference in the nature of the *substance*, or in diameter, i e, *mass*, or in *length*, very easy, and the obstruction offered by those parts, which moving not across but parallel to the lines of force (3071), have no exciting action but perform the part of conductors merely, might be greatly removed by making them massive They might be made to shift upon the axle so as to bear adjustment for different lengths of wires, and the commutator might in fact be made to a large extent a general instrument

3214 In looking forward to further applications of the principle of the moving wire, it does not seem at all unlikely that by increased delicacy and perfection of the instrument, by increased velocity, by continued motion for a time in one direction and then reversal of the revolution with the reversal of the direction of the swing &c, it may be applied with advantage hereafter to the investigation of the earth's magnetic force in different latitudes and places To obtain the maximum effect, the axis of rotation must be perpendicular to the lines of force, i e, the dip It would even be possible to search for the *direction* of the lines of force, or the dip, by making the axis of rotation variable about the line of dip, adjusting it in two directions until there was no action at the galvanometer, and then observing the position of the axis, a double commutator would be required corresponding to the lines of adjustment, but that is an instrument of very simple construction

§ 36 *On the Amount and General Disposition of the Forces of a Magnet when Associated with Other Magnets*

3215 Prior to further progress in the experimental development by a moving wire of the disposition of the lines of magnetic force pertaining to a magnet, or of the physical nature of this power and its possible mode of action at a distance, it became quite essential to know what change, if any, took place in the amount of force possessed by a perfect magnet, when subjected to other magnets in favourable or adverse positions, and how the forces combined together, or were disposed of, i e, generally, and in relation to the principle already asserted and I think proved, that the power is in every case definite under those different conditions The representation of the magnetic power by *lines of force* (3074), and the employment of the moving wire as a test of the force (3076), will I think assist much in this investigation

3216 For such a purpose an ordinary magnet is a very irregular and imperfect source of power It not only, when magnetized to a given degree, is apt by slight circumstances to have its magnetic power diminished or exalted, in a manner which may be considered for the time, permanent, but if placed in adverse or favourable relations to other magnets, frequently admits of a considerable temporary diminution or increase of its power externally, which change disappears as soon as it is removed from the neighborhood of the dominant magnet These changes produce corresponding effects upon the moving wire, and they render any magnet subject to them unfit for investigation in relation to definite power Unchangeable magnets are, therefore, required, and these are best obtained, as is well known, by selecting good steel for the bars, and then making them exceedingly hard, I therefore procured some plates of thin steel twelve inches long and one inch broad, and making them as hard as I could,

[1] $\sin \frac{5\ 995}{2} = \sin 2°\ 9975 = \sin 2°\ 59'\ 85 =$ 0522925

$\sin \frac{12\ 375}{2} = \sin 6°\ 1875 = \sin 6°\ 11'.25 =$ 1077825 $\frac{1077825}{2} =$ 0538912

afterwards magnetized them very carefully

ings Small cracks and irregularities were in this way detected in several of them but two which were very regular in the disposition of their forces were selected for further experiment and may be distinguished as the subjected magnets D and E

3217 The ...

ing it and again observing the swing and taking an average of many results the process was performed over both poles at different times The loop contained 7 25 inches in length of copper wire 0 1 of an inch in diameter and was of course employed in all the following comparative experiments the distance of the loop ...

lines of force of the other bar E the deflection was 8° 78 The two bars were then placed side by side with like poles together and afterwards used as one magnet their conjoined power was 16° 3 being only 0° 84 less than the sum of the powers of the two when estimated separately This indicates that the component magnets do affect and in this position reduce each other somewhat but it also shows how small the effect is as compared ...

times under favourable conditions and was ...

Figure 8 the loop in each case being applied ...

tion of 25° 74

3219 When the relative position of the magnets was as at 1 then the power of D E was 16° 37 when as at 2 the power was 16° 4 when as at 3 it was 18° 75 and when as at 4 it was 17° 18 All these positions are such as would tend to raise by induction the power of the magnet D E and they do raise it above its first value which was 16°.3 but it is seen at once

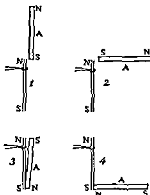


Fig 8

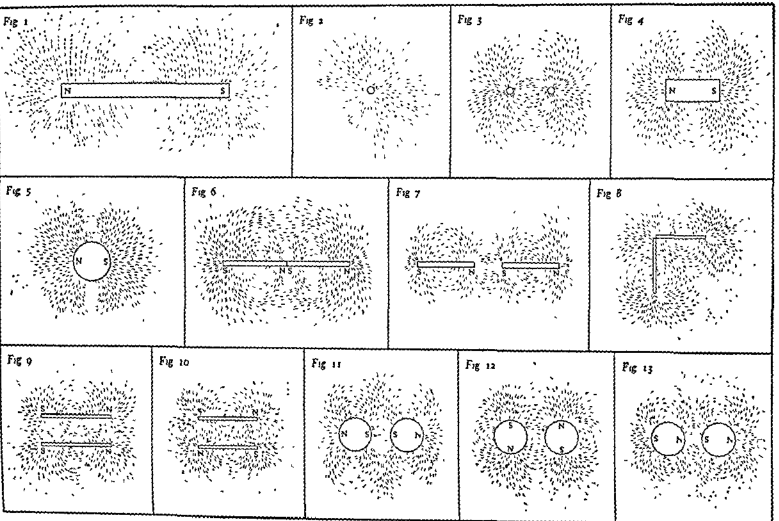
position

3220 Then the dominant magnet *A* was placed in the same positions but with the ends reversed so as to exert an adverse or depressing influence and now the results with *D E* were as follows

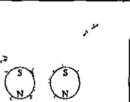
Position 1	15° 37
Position 2	15° 63
Position 3	15° 37
Position 4	16° 06

All these are a little below the original force of D E or 16° 3 as they ought to be and show how slightly this hard bar magnet is affected

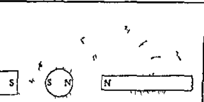
ployed instead of the hard magnet D E great changes took place Thus a bar B corresponding to bar A in size and general character was employed in place of the hard magnet Alone


Fig 1
N
S
Fig 2
Fig 3
Fig 4
N
S
Fig 5
N
S
Fig 6
S
N S
N
Fig 7
S
N
S
N
Fig 8
Fig 9
S
N
S
N
Fig 10
S
N
N
S
Fig 11
N
S
S
N
Fig 12
S
N
N
S
Fig 13
S
N
S
N

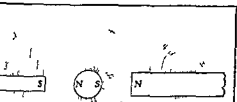
XVI



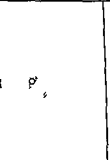
Fg 14

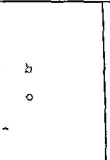


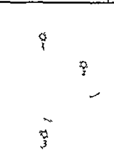
Fg 15

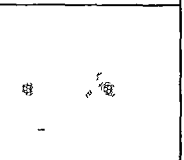


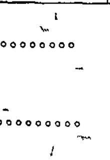
Fg 6

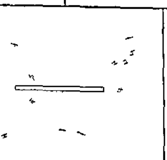

Fg 17

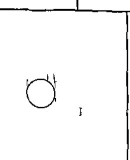

Fg 18

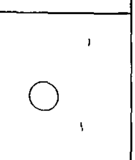

Fg 19


Fg 20


Fg 21


Fg 22


Fg 23


Fg 24

removed, B rose again to 13° 06 When B was laid for a few moments favourably on A and then removed, it was found that the latter had been raised to a permanent external action of 15°.25

3223 A very hard steel bar 6 inches long 0 5 broad and 0 1 in thickness given to me by Dr Scoresby, was magnetized and then found by the use of the loop to have a value at my galvanometer of 6° 88 (3189) It was submitted in position 2 to a compound bar magnet like D E, having a power of 11° 73, or almost twice its own force, but whether in the adverse or the *favourable position its power was not sensibly* altered When submitted in like manner to a 12 inch bar magnet having a force of 40° 21, it was raised to 7° 53 or lowered to 5° 87, but here the dominant magnet had nearly six times the power of the one affected

3224 The variability of soft steel magnets, both in respect to their *absolute* degree of excitation or charge, and also of the disposition of *the force externally and internally*, when their degree of excitation may for the time be considered as the same is made very manifest by this mode of examination and the results agree well with our former knowledge in this respect It is equally manifest that hard and invariable magnets are requisite for a correct and close investigation of the disposition and characters of the magnetic force A common soft bar magnet *may be considered as an assemblage of hard* and soft parts disposed in a manner utterly uncertain, *of which* some parts *take* a much higher charge than others and change less under the influence of external magnets, whilst, because of the presence of other parts within, acting as the keeper or submagnet, they may seem to undergo far greater changes than they really do Hence the value of these hard and comparatively unchangeable magnets which Scoresby describes

3225 *From these and such results it appears* to me, that with perfect, unchangeable magnets and using the term *line of force* as a mere representant of the force as before defined (3071, 3072), the following useful conclusions may be drawn

3226 Lines of force of different magnets in favourable positions to each other coalesce

3227 There is no increase of the total force of the lines by this coalescence the section between the two associated poles gives the same sum of power as *that of the section of the lines* of the invariable magnet when it is alone (3217) Under these circumstances *there is, I think, no* doubt that the external and internal forces of the same magnet have the same relation and are equivalent to each other, as was determined in a former part of these *Researches* (3117) *and that therefore the equatorial section*, which represents the sum of forces or lines of forces passing *through the magnet*, remains also unchanged (3232)

3228 In this case the analogy with two or more voltaic batteries associated end to end in one circuit is perfect Probably some effect, correspondent to *intensity* in the case of the batteries, will be found to exist amongst the magnets

3229 The increase of power upon a magnetic needle, or piece of soft iron placed between two opposite, favourable poles, is caused by concentration upon it of the lines which before were diffused, and not by the addition of the power represented by the lines of force of one *pole to that of the lines of force of the other* There is no more power represented by all the lines of force than *before*, and a *line of* force is not more powerful because it coalesces with a line of force of another magnet *In this* respect the analogy with the voltaic pile is also perfect

3230 A line of magnetic force being considered as a closed circuit (3117), passes in its course through *both* the magnets, which are for the time placed so as to act on each other *favourably, i e, whose lines coincide and coalesce* Coalescence is not the addition of one *line of force to another in power, but their union* in one common circuit

3231 *A line of force may pass through many* magnets before its circuit is complete and these many magnets coincide as a case with that of a single magnet If a thin bar-magnet 12 inches long be examined by filings (3235), it will be found to present the well known beautiful system of forces, perfectly simple in its *arrangement* *If it be broken in half, without being* separated, and again examined the manner in which, *from the destruction of the continuity*, the transmission of the force at the equator is interfered with, and many of the lines which before were within are made to appear externally there, is at once evident (Pl XVI, *Fig 6*) Of those lines, which thus become external, some return back to the pole which is nearest to the new place, at which the lines issue into the air, making their circuit through only one *of the halves of the magnet*, whilst others proceed onward by paths more or less curved into *the second half of the magnet, keeping gener-*

ally the direction or polarity which they had whilst ...

serve how more and more of the lines which issue from the two new terminations, turn back to the original extremities of the bar (Pl XVI, Fig 7) and how the portion which makes a common circuit through the two halves diminishes until the halves are entirely removed from each other's influence, and then become two separate and independent magnets The same process may be repeated until there are many magnets in place of one

3232 All this time the amount of lines of force is the same if the fragments of the bar preserve their full state of magnetism, i e the sum of lines of force in the equator of *either* of the new magnets is equal to the sum of lines of force in the equator of the original unbroken bar I took a steel bar 12 inches long, 1 inch broad and 0 05 of an inch thick made it very hard, and magnetized it to saturation by the use of soft iron cores and a helix, its power was 6° 9 I broke it into two pieces nearly in the middle, and found the power of these respectively 5° 94 and 5° 89 indicating a fall not more than ...

below the sum of their powers ascertained separately All this is in perfect harmony with the voltaic battery, where lines of dynamic electric force are concerned If, as is well known, we separate a battery of 20 pair of plates into two batteries of 10 pair, or 4 batteries of 5 pair, each of the smaller batteries can supply as much dynamic electricity as the original battery, provided no sensible obstruction be thrown into the course of the lines, i e the path of the current

3233 When magnets are placed in an adverse position, as neither could add power to the other in the former case so now each retains its own power and the lines of magnetic force ... Two mag...

portion which, as in imperfect magnets, is either directed inwards by the softer parts or ceases to be excited altogether

§ 37 *Delineation of Lines of Magnetic Force by Iron Filings*

3234 It would be a voluntary and unnecessary abandonment of most valuable aid if an experimentalist, who chooses to consider magnetic power as represented by lines of magnetic force, were to deny himself the use of iron filings By their employment he may make many conditions of the power, even in complicated cases visible to the eye at once may trace the varying direction of the lines of force and determine the relative polarity, may observe in which direction the power is increasing or diminishing, and in complex systems may determine the neutral points or places where there is neither polarity nor power, even when they occur in the midst of powerful magnets By their use probable results may be seen at once, and many a valuable suggestion gained for future leading experiments

3235 Nothing is simpler than to lay a magnet upon a table, place a flat piece of paper over it, and then sprinkling iron filings on the paper, to observe the forms they assume Nevertheless to obtain the best and most generally useful results a few particular instructions may be desirable The table on which the magnet is laid should be quite horizontal and steady Means should be taken by the use of thin boards or laths or otherwise to block up round the magnet, so that the paper which is laid over it should be level The paper should be ...

when slightly agitated, move too freely towards the magnet With very weak or distant ...

also fine filings are equally useful in turn, when the object is to preserve the forms obtained For the distribution of the latter it is better to use a fine sieve with the ordinary filings than to separate the filings first a better distribution on the paper is obtained The filings being sifted evenly on the paper, the latter should be tapped very lightly by a small piece of wood, as a pen holder, the taps being applied wherever the particles are not sufficiently arranged The taps must be perpendicularly downwards, not obliquely so that the particles, whilst they have the liberty of motion, for an instant are not driven out of their places, and the paper should be held down firmly at one corner so as not to shift right or left the lines are instantly formed, especially with fine filings

3236 The designs thus obtained may be fixed in the following manner, and then form very valuable records of the disposition of the forces in any given case By turning up two corners of the paper on which the filings rest they may be used as handles to raise the paper upwards from the magnet, to be deposited on a flat board or other plane surface A solution of one part of gum in three or four of water having been prepared a coat of this is to be applied equably by a broad camel-hair pencil, to a piece of cartridge paper, so as to make it fairly wet, but not to float it, and after waiting it through the air once or twice to break the bubbles, it is to be laid carefully over the filings, then covered with ten or twelve folds of equable soft paper, a board placed over the paper, and a half hundred weight on the board for thirty or forty seconds Or else, and for large designs it is a better process, whilst the papers are held so that they shall not shift on each other, the hand should be applied so as to rub with moderate pressure over all the surface equably and in one direction If after that, the paper be taken up, all the filings will be found to adhere to it with very little injury to the forms of the lines delineated, and when dry they are firmly fixed If a little solution of the red ferroprussiate of potassa and a small proportion of tartaric acid be added to the gum water, a yellow tint is given to the paper, which is not unpleasant, but besides that, prussian blue is formed under every particle of iron and then when the filings are purposely or otherwise displaced the design still remains recorded When the designs are to be preserved in blue only, the gum may be dispensed with and the red ferroprussiate solution only be used

3237. It must be well understood that these forms give no indication by their appearance of the relative strength of the magnetic force at different places, inasmuch as the appearance of the lines depends greatly upon the quantity of filings and the amount of tapping but the direction and forms of the lines are well given, and these indicate, in a considerable degree the direction in which the forces increase and diminish

3238 Pl XVI, Fig 1, shows the forms assumed about a bar magnet On using a little electro magnet and varying the strength of the current passed through it I could not find that a variation in the strength of the magnet produced any alteration in the forms of the lines of force external to it Fig 2 shows the lines over a pole, and Fig 3 those between contrary poles The latter accord with the magnetic curves, as determined and described by Dr Roget and others, with the assumption of the poles as centres of force The difference between them and those belonging to a continuous magnet shown in Fig 1, is evident Figs 4, 5 show the lines produced by short magnets In the latter case the magnet was a steel disc about one inch in diameter and 0 05 in thickness Fig 6 shows the result when a bar magnet is broken in half, but not separated Fig 7 shows the development of the lines externally at the two new ends as the halves are more and more separated (3231) Figs 8, 9 and 10 present the results with the two halves or new magnets in different positions Figs 11, 12, 13 and 14 show the results with disc magnets Fig 15 shows the condition of a system of magnetic forces when it is inclosed by a larger one, and is contrary to it Fig 16 shows the coalescence of the lines of force (3226) when the magnets are so placed that the polarities are in accordance

3239 Pl XVI, Fig 17 exhibits the lines of force round a vertical wire carrying a current of electricity Whether the wire was thick or thin appeared to make no difference as to the intensity of the forces, the current remaining the same Fig 18 represents the lines round two like currents when within mutual influence Fig 19 shows the result when a third current is introduced in the contrary direction Fig 20 presents the transition to a helix of three convolutions Fig 21 indicates the direction of the lines within and outside the end of a cylindrical helix, on a plane through its axis Fig 22 presents the effect when a very small soft iron core is within the helix

3240 Pl XVI, *Figs* 23 and 24, give an experimental illustration of the principles which I have adopted in relation to atmospheric magnetism and the general cause of the daily variations, &c. (2864, 2917). A hemisphere of pure nickel

inches from the nickel, and thus the forms of the lines of force associated with this pole could be determined over the place of the nickel hemisphere, under different circumstances, or even when it was removed When the nickel was away, the forms of the lines of force were as in *Fig* 23, when the nickel was there, they were as in *Fig* 24. The application of a spirit-lamp to the nickel when in its place, raised its temperature to such a degree (above 600° Fahr.) that it lost its ordinary magnetic condition, and then the forms of the lines of force, as

pieces of paper, and as many as four results, like *Fig* 23, could be procured before the temperature had sunk so much as to cause the production of lines of force corresponding to *Fig* 24.

3241 These are exactly the same results with nickel as those I have assumed for the oxygen of the atmosphere The change in the forms of the lines about the cooling nickel in this experiment are the same changes as those I have figured in the type globe of cooling air (2865,

through the atmosphere, correspondent to those of the heating and cooling nickel, *must* take place to some extent It is seen in the nickel results that lines of force entirely outside of it do not for that reason continue an undeviating course, but are curved to and fro in consequence of the disposition of other lines within the nickel, a result which, without reference to either one view or another of the physical action of the magnetic force, must be as true in the oxygen case as in the nickel case, because of the definite character of the magnetic force, whether represented by centres of action or by lines of power.

3242 Whether the amount of the deflection in the case of the atmosphere corresponds with the facts registered by observers, is a question which cannot be answered, I suppose, until we know the effect of very low temperatures upon the magnetic force of the atmosphere In the nickel experiment the deflection is in places 30° or 40°, in nature the effect to be accounted for is not more than 13 or 14 minutes

Royal Institution, December 20, 1851

Papers on Electricity from the Quarterly Journal of Science, Philosophical Magazine, *&c*

more nearly perfect

PLATE XVII

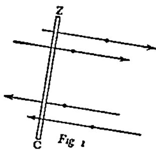


Fig 1

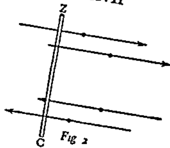


Fig 2

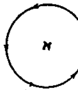


Fig 4

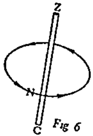


Fig 6

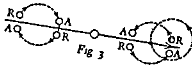


Fig 3

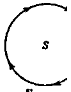


Fig. 5

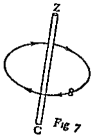


Fig 7

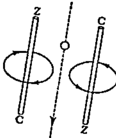
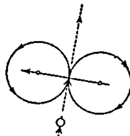
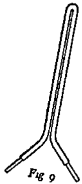
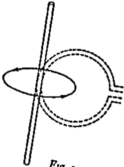
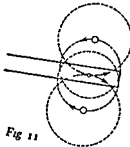


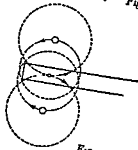
Fig 8


Fig. 10


Fig 9


Fig 14


Fig 11


Fig. 12

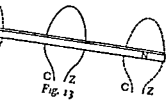


Fig. 13


Fig. 15


Fig. 16

diagrams I m

seen from above, and the arrow heads have been used sometimes to mark the pole of a needle or magnet which points to the north, and sometimes to mark the direction of motion no difficulty can occur in ascertaining to which of those uses any particular head is applied

On placing the wire perpendicularly, and bringing a needle towards it to ascertain the attractive and repulsive positions with regard to the wire, instead of finding these to be four, one attractive and one repulsive for each pole I f

by Oersted for the reason before mentioned, and then drawing the support away from the wire slowly, so as to bring the north pole, for instance, nearer to it there is attraction as is to be expected but on continuing to make the end of the needle come nearer to the wire, repulsion takes place though the wire still be on the same side of the needle If the wire be on the other side of the same pole of the needle it will repel it when opposite to most parts between the centre of motion and the end but there is a small portion at the end where it attracts it Pl XVII *Fig 1* shows the positions of attraction for the north and south poles

needle powerfully endeavours to pass the opposite way

It is evident from this that the centre of the active portion of either limb of the needle, or the true pole as it may be called is not at the extremity of the needle but may be represented by a point generally in the ax

at some little distance from the end It was evident, also, that this point had a tendency to

had the power of acting on the wire by itself, and not as any part of the needle, or as con

tions to the needle, all this will be plain the active poles are represented by two dots and the arrow heads show the tendency of the wire in its positions to go round these poles

Several important conclusions flow from

pound actions that true magnetic poles are centres of action induced by the whole bar &c, &c Such of these as I have been able to confirm by experiment, shall be stated, with their proofs

The revolution of the wire and the pole round each other being the first important thing required to prove the nature of the force mutually exerted by them, various means were tried to succeed in producing it The difficulty con-

an upper centre of motion, for a lower centre, a similar cup was made of copper, into which a little mercury was put, this was placed in a jar of water under the former centre A piece of copper wire was then bent into the form of a

the wire very mobile yet with good contacts The plates being then connected with the two

state, a magnetic pole being brought to the centre of motion of the crank, the wire immediately made an effort to revolve until it struck the magnet, and that being rapidly brought round to the other side, the wire again made a revolution, giving evidence that it would have gone round continually but for the extension of the magnet on the outside To do away with this impediment, the wire and lower metal cup were removed, and a deep basin of mercury placed beneath, at the bottom of this was a piece of wax, and a small round bar magnet was stuck upright in it, so that one pole was about half or three fourths of an inch above the surface of the mercury, and directly under the silver cup A straight piece of copper wire, long enough to reach from the cup, and dip about half an inch into the mercury, had its ends amalgamated, and a small round piece of cork fixed on to one *of them to make it more buoyant*, this being dipped in the mercury close beside the magnet, and the other end placed under the little cup, the wire remained upright, for the adhesion of the cork to the magnet was sufficient for that purpose, and yet at its lower end had freedom of motion round the pole The connection being now made from the plates to the upper cup, and to the mercury below, the wire immediately began to revolve round the pole of the magnet, and continued to do so as long as the connection was continued

When it was wished to give a large diameter to the circle described by the wire, the cork was removed from the magnet, and a little loop of platinum passed round the magnet and wire, to prevent them from separating too far Revolution again took place on making the connection, but more slowly as the distance increased

The direction in which the wire moved was according to the way in which the connections were made, and to the magnetic pole brought into action When the upper part of the wire was connected with the zinc, and the lower with the copper plate, the motion round the north and south poles of a magnet were as in Pl XVII, *Figs 4* and *5*, looking from above, when the connections were reversed, the motions were in the opposite direction

On bringing the magnetic pole from the centre of motion to the side of the wire, there was neither attraction nor repulsion but the wire endeavoured to pass off in a circle still having the pole for its centre, and that either to the one side or the other, according to the above law

When the pole was on the outside of the wire, the wire moved in a direction directly contrary to that taken when the pole was in the inside, but it did not move far, the endeavour was still to go round the pole as a centre, and it only moved till that power and the power which retained it in a circle about its own axis were equipoised

The next object was to make the magnet revolve round the wire This was done by so loading one pole of the small magnet with platinum that the magnet would float upright in a basin of mercury, with the other pole above its surface, then connecting the mercury with one plate and bringing a wire from the other perpendicularly into it in another part near the floating magnet the upper pole immediately began to revolve round the wire, whilst the lower pole being removed away caused no interference or counteracting effect

The motions were again according to the pole and the connections When the upper part of the wire was in contact with the zinc plate, and the lower with the copper, the direction of the curve described by the north and south poles was as in Pl XVII, *Figs 6* and *7* When the connections were reversed, the motions were in the opposite directions

Having succeeded thus far, I endeavoured to make a wire and a magnet revolve on their own axis by preventing the rotation in a circle round them, but have not been able to get the slightest indications that such can be the case, nor does it on consideration, appear probable The motions evidently belong to the current, or whatever else it be that is passing through the wire, and not to the wire itself, except as the vehicle of the current When that current is made a curve by the form of the wire, it is easy to conceive how, in revolving it should take the wire with it but when the wire is straight, the current may revolve without any motion being communicated to the wire through which it passes

M Ampère has shown that two similar connecting wires, by which is meant, having currents in the same direction through them attract each other, and that two wires having currents in opposite directions through them, repel each other, the attraction and repulsion taking place in right lines between them From the attraction of the north pole of a needle on one side the wire, and of the south on the other, and the repulsion of the poles on the opposite sides, Dr Wollaston called this magnetism *vertiginous*, and conceived that the

phenomena might be explained upon the sup position of an electro-magnet...

M Ampère's wires are not simple, but complicated results

A simple case which may be taken of magnetic motion is the circle described by the wire or the pole...

trated in the axis of the helix, whilst the contrary kind is very much diffused, i e, the power exerted by a great length of wire to make a pole pass one way round it, all tends to carry that pole to a particular spot, whilst the opposite power is diffused and much weakened in its action on any one pole Hence the power on one side of the wire is very much concentrated, and its particular effects brought out strongly...

When this is done, and we examine the end of the helix, it is found very much to resemble a magnetic pole, the power is concentrated at the extremity of the helix, it attracts or repels one pole in all directions, and I find that it causes the revolution of the connecting wire round it, just as a magnetic pole does Hence it may, for the present, be considered identical with a magnetic pole, and I think that the experimental evidence of the ensuing pages will much...

ne

sic

with the wire itself offer us a means of analysis...

side by which it is attracted, and from that side by which it is repelled, i e, the pole is at once attracted and repelled by equal powers,

The phenomena presented by the approximation of one pole to two or more wires, or two poles to one or more wires, offer many illustrations of this double action, and will lead to more correct views of the magnet These experiments are easily made by loading a needle with platinum at one pole, that the other may float above mercury, or by almost floating a small magnetic needle by cork in a basin of water, at the bottom of which is some mercury with which to connect the wires In describing them I shall refrain from entering into all their variations, or pursuing them to such conclusions as are not directly important

Two similar wires, Ampère has shown, attract each other, and Sir H Davy has shown that the filings adhering to them attract from one to another on the same side They are in that position in which the north and south influence of the different wires attract each other They seem also to neutralize each other in the parts that face, for the magnetic pole is...

...to float... and to be at the farther...

revolves round them all, the internal wires appear to lose part of their force, which is carried on towards the extreme wire in opposite directions, so that the floating pole is ac...

wire from each other

If two wires in opposite states be arranged parallel to each other, and the pole be brought near them, it will circulate round either of them in obedience to the law laid down, but as the wires have opposite currents, it moves opposite directions round the two, so that

equidistant from them, the pole is propelled in a right line perpendicular to the line which joins them, either receding or approaching, and if it approaches, passing between and then receding, hence it exhibits the curious appearance of first being attracted by the two wires, and afterwards repelled (Pl XVII, *Fig 8*) If the connection with both wires be inverted, or if the pole be changed, the line it describes is in the opposite direction If these two opposite currents be made by bending a piece of silked wire parallel to itself, *Fig 9*, it, when connected with the apparatus becomes a curious magnet, with the north pole, for instance, it attracts powerfully on one side at the line between the two currents, but repels strongly to the right or left, whilst on the other side the line repels the north pole, but attracts it strongly to the right or left With the south pole the attractions and repulsions are reversed

When both poles of the needle were allowed to come into action on the wire or wires, the effects were in accordance with those described. When a magnetic needle was floated on water, and the perpendicular wire brought towards it, the needle turned round more or less, until it took a direction perpendicular to, and across the wire, the poles being in such positions that either of them alone would revolve round the wire in a circle proceeding by the side to which it had gone, according to the law before stated The needle then approaches to the wire, its centre (not either pole) going in a direct line towards it. If the wire be then lifted up and put down the other side of the needle, the needle passes on in the same line receding from the wire, so that the wire seems here to be both attractive and repulsive of the needle This effect will be readily understood from Pl XVII, *Fig 10*, where the poles and direction of the wire are not marked, because they are the same as before If either be reversed, the others reverse themselves The experiment is analogous to the one described above, there the pole passed between two dissimilar wires, here the wire between two dissimilar poles

If two dissimilar wires be used, and the magnet have both poles active, it is repelled, turned round, or is attracted in various ways, until it settles across between the two wires, all its motions being easily reducible to those impressed on the poles by the wires, both wires and both poles being active in giving that position. Then if it happens not to be midway between the two, or they are not of equal power, it goes slowly towards one of them, and acts with it just as the single wire of the last paragraph

Pl XVII, *Figs 11* and *12* exhibit more distinctly the direction of the forces which influence the poles in passing between two dissimilar wires *Fig 11*, when the pole draws up between the wires, *Fig 12*, the pole thrown out from between them The poles and state of the wire are not marked, because the diagrams illustrate the attraction and repulsion of both poles, for any particular pole, the connection of the wires must be accordingly

If one of the poles be brought purposely near either wire in the position in which it appears to attract most strongly, still if freedom of motion be given by a little tapping, the needle will slip along till it stands midway across the wire.

A beautiful little apparatus has been made by M de la Rive to whom I am indebted for one of them, consisting of a small voltaic combination floating by a cork the ends of the little zinc and copper slips come through the cork, and are connected above by a piece of silked wire which has been wrapped four or five times round a cylinder, and the wires tied together with a silk thread so as to form a close helix about one inch in diameter When placed on acidulated water it is very obedient to the magnet and serves admirably to transform as it were, the experiments with straight wires that have been mentioned, to the similar ones made with helices Thus, if a magnet be brought near it and level with its axis, the apparatus will recede or turn round until that side of the curve next to the nearest pole is the side attracted by it It will then approach the pole, pass it, recede from it until it gains the middle of the magnet, where it will rest like an equator round it, its motions and position being still the same as those before pointed out (Pl XVII, *Fig 13*) If brought near either pole it will still return to the centre, and if purposely placed in the opposite direction at the centre of the magnet, it will pass off by either pole to which it happens to be nearest, being apparently first attracted by the pole and afterwards repelled, as is actually the case will, if any circumstance disturbs its perpendicularity to the magnet, turn half way round, and will then pass on to the magnet again, into the position first described. If, instead of passing the magnet through the curve, it be held over it, it stands in a plane perpendicular to the magnet, but in an opposite direction to the former one So that a magnet, both within and without this curve, causes it to direct.

When the poles of the magnet are brought over this floating curve there are some movements and positions which at first appear anomalous but are by a little attention easily reducible to the circular movement of the wire about the pole I do not think it necessary to state them *particularly*

The attractive and repulsive positions of this curve may be [illegible]

pulsion takes place

From the central situation of the magnet in these experiments it may be concluded that a strong and powerful curve or helix would suspend a powerful needle in its centre By making a needle almost float on water and putting the helix over a glass tube this result has in part been obtained

In all these magnetic movements between [illegible]

[illegible]

magnets or in the opposite sides of conducting wires This being admitted the simplest cases of magnetic action will be those exerted by the poles of helices for as they offer the magnetic states of the opposite sides of the wire independent or nearly so one of the other we are enabled by them to bring into action two of those [illegible]

[illegible] cases of magnetic motion in the order of simplicity are those where three powers are concerned or those produced by a pole and [illegible]

the wire round each other The law which governs these motions has been stated

[1] This is perhaps not strictly true because, though the opposite powers are weakened they still remain in action

Then follow the [illegible]

sides of the wire the same powers are opposed and cause a double repulsion

[illegible]

[illegible] 10)

The motions of a pole with two wires are almost the same as the last when the wires are dissimilar the pole endeavours to form two opposite circles about the wires when it is on that side of the wires on which the circles meet it is attracted when on the side on which they open it is repelled (Pl XVII *Figs 8 11 12*)

Finally the motion between two poles and two dissimilar wires is an instance where several powers combine to produce an effect

M Ampère whilst reasoning on the discovery of M Oersted was led to the adoption of a theory by which he endeavoured to account for the properties of magnets by the ex[illegible]

round the axis of a cylinder The ends of such helices were found when connected with the [illegible]

specting the competency of this theory might be gained from an attempt to trace the action of the helix and compare it with that of the magnet more rigorously than had yet been done and to form artificial electro-magnets and analyse natural ones In doing this I think I have so far succeeded as to trace the action of an electro-magnetic pole either in attracting or repelling to the circulating motion bef

If three inches of connecting wire be taken, and a magnetic pole be allowed to circulate round the middle of it, describing a circle of a little less than one inch in diameter, it will be moved with equal force in all parts of the circle (Pl XVII, *Fig 14*), bend then the wire into a circle, leaving that part round which the pole revolves perpendicularly undisturbed, as seen by the dotted lines, and make it a condition that the pole be restrained from moving out of the circle by a radius It will immediately be evident that the wire now acts very differently on the pole in the different parts of the circle it describes *Every part of it will be active at the same time on the pole, to make it move through the centre of the wire ring*, whilst as it passes away from that position the powers diverge from it, and it is either removed from their action or submitted to opposing ones, until on its arriving at the opposite part of the circle it is urged by a very small portion indeed of those which moved it before As it continues to go round its motion is accelerated, the forces rapidly gather together on it, until it again reaches the centre of the wire ring where they are at their highest, and afterwards diminish as before Thus the pole is perpetually urged in a circle, but with powers constantly changing

If the wire ring be conceived to be occupied by a plane, *then the centre of that plane is the spot where the powers are most active on the pole, and move it with most force* Now this spot is actually the pole of this magnetic apparatus It seems to have powers over the circulating pole making it approach or attracting it on the one side, and making it recede or repelling it on the other, with powers varying as the distance, but its powers are only apparent, for the force is in the ring, and this spot is merely the place where they are most accumulated, and though it seems to have opposite powers, namely those of attracting and repelling yet this is merely a consequence of its situation in the circle, the motion being uniform in its *direction, and really and truly impressed on the pole by its motor, the wire*

At page 799 it was shown that two or more similar wires put together in a line, acted as one, the power being, as it were, accumulated towards the extreme wires, by a species of induction taking place among them all, and at the same time was noticed the similar case of a plate of metal connecting the ends of the apparatus, its powers being apparently strongest at the edges If, then, a series of concentric rings be placed one inside the other, they having the electric current sent through them in the same direction, of if, which is the same thing, a flat spiral of silked wire passing from the centre to the circumference be formed, and its ends be in connection with the battery (Pl XVII, *Fig 15*), then the circle of revolution would still be as in *Fig* 14, passing through the centre of the rings or spiral, but the power would be very much increased Such a spiral, when made, beautifully illustrates this fact it takes up an enormous quantity of iron filings, which approach to the form of cones, *so strong is the action at the centre, and its action on the needle by the different sides, is eminently powerful*

If in place of putting ring within ring they be placed side by side, so as to form a cylinder, or if a helix be made, then the same kind of neutralization takes place in the intermediate wires, and accumulated effect in the extreme ones, as before The line which the pole would now travel, supposing the inner end of the radius to move over the inner and outer surface of the cylinder, would be through the axis of the cylinder round the edge to one side, back up that side, and round to the axis, down which it would go, as before In this case the force would probably be greatest at the two extremes of the axis of the cylinder, and least at the middle distance on the outside

Now consider the internal space of the cylinder filled up by rings or spirals all having the currents in the same direction the direction and kind of force would be the same, but very much strengthened it would exist in the strongest degree down the axis of the mass, because of the circular form and it would have the two sides of the point in the centre of the simple ring, which *seemed* to possess attractive and repulsive powers on the pole removed to the ends of the cylinder, giving rise to two points, apparently distinct in their action, one being *attractive*, and the other *repulsive, of the poles* of a magnet *Now conceive that the pole is not confined to a motion about the sides of the ring or the flat spiral, or cylinder*, it is evident that if placed in the axis of any of them at a proper distance for action, it, being impelled by two or more powers in equal circles, would move in a right line in the intersection of those circles, and approach directly to or recede from, the points before spoken of, giving the appearance of a direct attraction and repulsion, and if placed out of that axis, it would move towards or from the same spot in a curve line,

its direction and force being determined by the curve lines representing the active forces from the portions of wire forming the ends of the cylinder, spiral, or ring and the strength of those forces.

Thus the phenomena of a helix or a solid cylinder of spiral silked wire are reduced to the simple revolution of the magnetic pole

ranged themselves in curved lines passing from one end to the other showing the path the pole would follow and so they do over a mag-

of a magnet

A small magnet being nearly floated in water

endeavouring to go round the wire The actions also presented by M de la Rive s ring are actions of this kind and indeed are those which best illustrate the relations between the ring

very much increased and when the rings were not continued to the centre the power of the

and instructive when laid flat up

them they arranged themselves in lines passing through the ring parallel to its axis and then folding up on either side as radii round to the edge where they met so that they repre-

with what has been described whilst the intermediate portion also formed long threads, bending this way and that from the centre more or less according as they were farther from or nearer to it

the needle was

the glass tube but did not stop just within side in the neighbourhood of this pole (as we may call it for the moment) of the helix but

pole entered the tube and passed to the other end taking the whole needle into the same position it was in before

Thus each end of the helix seemed to attract and repel both poles of the needle but this is

only a natural consequence of the circulating motion before experimentally demonstrated, and each pole would have gone through the helix and round on the outside, but for the counteraction of the opposite pole It has been stated that the poles circulate in opposite directions round the wires, and they would consequently circulate in opposite directions through and round the helix when, therefore, one end of the helix was near that pole, which would according to the law stated, enter it and endeavour to go through it would enter, and it would continue its course until the other pole, at first at a distance, would be brought within action of the helix and, when they were both equally within the helix and consequently equally acted on, their tendency to go in different directions would counterbalance each other, and the needle would remain motionless If it were possible to separate the two poles from each other, they would dart out of each end of the helix, being apparently repelled by those parts that before seemed to attract them, as is evident from the first and many other experiments

By reversing the needle and placing it purposely in the helix in that position, the poles of the needle and the corresponding poles of the helix as they attract on the outside, are brought together on the inside, but both pairs now seem to repel and, whichever end of the helix the needle happens to be nearest to, it will be thrown out at This motion may be seen to exhibit in its passing state, attraction between similar poles, since the inner and active pole is drawn towards that end on the inside, by which it is thrown off on the outside [1]

These experiments may be made with the single curve of M de la Rive, in which case it is the wire that moves and not the magnet, but as the motions are reciprocal, they may be readily anticipated

A plate of copper was bent nearly into a cylinder, and its edges made to dip into two portions of mercury, when placed in a current it acted exactly as a helix

A solid cylinder of silked wire was made exactly in fashion like a helix, but that one length of the wire served as the axis, and the folds were repeated over and over again This as well as the former helix, had poles the same in every respect as to kind as the north and south poles of a magnet, they took up filings, they made the connecting wire revolve, they attracted and repelled in four parallel positions as is described of common magnets in the first pages of this paper, and filings sprinkled on paper over them, formed curves from one to the other as with magnets; these lines indicating the direction in which a north or south pole would move about them

Now with respect to the accordance which is found between the appearances of a helix or cylinder when in the voltaic circuit, and a cylindrical common magnet, or even a regular square bar magnet, it is so great, as at first to leave little doubt, that whatever it is that causes the properties of the one, also causes the properties of the other, for the one may be substituted for the other in, I believe, every magnetical experiment, and, in the bar magnet, all the effects on a single pole or filings &c , agree with the notion of a circulation, which if the magnet were not solid would pass through its centre, and back on the outside

The following, however, are differences between the appearances of a magnet and those of a helix or cylinder one pole of a magnet attracts the opposite pole of a magnetic needle in all directions and positions but when the helix is held alongside the needle nearly parallel to it, and with opposite poles together, so that attraction should take place, and then the helix is moved on so that the pole of the needle gradually comes nearer to the middle of the helix, repulsion generally takes place before the pole gets to the middle of the helix, and in a situation where with the magnet it would be attracted This is probably occasioned by the want of continuity in the sides of the curves or elements of the helix, in consequence of which the unity of action which takes place in the rings into which a magnet may be considered to be divided is interfered with and disturbed

Another difference is that the poles, or those spots to which the needle points when perpendicular to the ends or sides of a magnet or helix, and where the motive power may be considered perhaps as most concentrated, are in the helix at the extremity of its axis, and not any distance in from the end, whilst in the most regular magnets they are almost always situate in the axis at some distance in from the end a needle pointing perpendicularly towards the end of a magnet is in a line with its axis, but perpendicularly to the side, it points to a spot some distance from the end, whilst in the helix, or cylinder, it still points to the end This varia-

[1] The magnetizing power of the helix is so strong that if the experiment be made slowly the needle will have its magnetism changed and the result will be fallacious.

sarily uniform everywhere, inasmuch as the current of electri

united in the inner part of the bar have the same power Thus a piece of soft iron put to one end of

that if it were complete, the two poles of the magnet would be diffused over the whole of its mass, the instrument there exhibiting no attractive or repulsive powers Hence it is not improbable that, caused by some induction a greater accumulation of power may take place in the middle of the magnet than at the end, and may cause the poles to be inwards, rather than at the extremities

A third difference is that the similar poles of magnets, though they repel at most distances, yet when brought very near together, attract each other This power is not strong but I do not believe it is occasioned by the superior strength of one pole over the other, since the most equal magnets exert it, and since the poles as to their magnetism remain the same, and are able to take up as much, if not more iron filings when together, as when separated, whereas opposite poles, when in contact, do not take up so much With similar helix poles, this attraction does not take place

The attempts to make magnets resembling the helix and the flat spirals, have been very

of a needle would have gone up the axis and down the sides, as with the helix, but would have stopped at the dissimilar pole of the needle Hence it is certain that the rings of which the cylinder may be supposed to be formed

the purpose of imitating the flat spiral (Pl XVII, *Fig 15*), failed, nothing but an irregular distribution of the magnetism could be obtained

M Ampère is I believe, undecided with regard to the size of the currents of electricity that are assumed to exist in magnets, perpen-

rections, the one on the inside, the other on the outside surface In another part, I believe, the

the direction required

as the copper wire of the helix magnet, and perhaps as M Ampère supports in his theory, by

Dr Wollaston is attached to the opinion that a

mental grounds As the magnet directs the wire when in form of a curve, and the curve a needle, I endeavoured to repeat the experiment, and succeeded in the following manner A voltaic combination of two plates was formed these were connected by a copper wire, bent into a

PLATE XVIII



Fig 3



Fig. 4

Fig 1



Fig 5

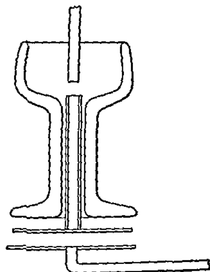


Fig 2

circular form, the plates were put into a small glass jar with dilute acid, and the jar floated on the surface of water Being then left to it-

the other

whole readily took the position mentioned above, and even vibrated slowly about it

magnetic pole of the earth, as with the pole of a magnet

tend to pass in a circle downwards, and in the other upwards This alteration should take

Electro-magnetic Rotation Apparatus[2]

Since the paper in the preceding pages has been printed, I have had an apparatus made by Mr Newman, of Lisle Street for the revolutions of the wire round the pole, and a pole round the wire When Hare's calorimoter was

one end of which a brass pillar rises about 6 inches high, and is then continued horizontal-

side in the middle is a similar plate and a wire, these are both fixed A small shallow glass cup, supported on a hollow foot of glass has a plate

poured in until the glass is nearly full, a rod of metal descends from the horizontal arm perpendicularly over this cup, a little cavity is hollowed at the end and amalgamated, and a piece of stiff copper wire is also amalgamated, and

beneath it

The other plate on the stand has also its cup,

[1] *Quarterly Journal of Science* XII 186
[2] *Ibid.*

[3] *Ibid* 253.

is given in the present number, presenting a

magnetic pole round the connecting wire of the voltaic battery is produced That a current of

per, forming part of the foot of the vessel A similar plate of copper is fixed to the turned wooden base on which the cup is intended to stand, and a piece of strong copper wire, which is attached to it beneath, after proceeding downwards a little way, turns horizontally to the left hand, and forms one of the connections The surfaces of these two plates intended to

and powerful magnet has one of its poles fastened to a piece of thread, which, at the other end, is attached to the copper pin at the bottom

free pole shall float almost upright on its surface

A small brass pillar rises from the stand be-

where it is perpendicularly over the cup just described, bends downwards, and is continued till it just dips into the centre of the mercurial surface The wire is diminished in size for a short distance above the surface of the mercury, and its lower extremity amalgamated, for

placed in it, and retained there by being fastened to a circular plate below, which is cemented to the glass foot, so that no mercury shall pass out by it This plate is tinned and amalgamated on its lower surface, and stands on another plate and wire, just as in the former instance A small circular bar magnet is placed in the socket, at any convenient height, and then mercury poured in until it rises so high that nothing but the projecting pole of the magnet is left above its surface at the centre The forms and relative positions of the magnet, socket, plate, &c, are seen in Pl XVIII, *Fig 2*

The cross wire supported by the brass pillar

inch it has its lower extremity hollowed out

size that it may play in the cup in the manner of a ball and socket joint, and being well amalgamated, it, when in the cup, retains sufficient fluid mercury by capillary attraction to form an excellent contact with freedom of motion The ball is prevented from falling out of the socket by a piece of fine thread, which, being fastened to it at the top, passes through a small hole at the summit of the cup, and is made fast on the outside of the thick wire This is more

revolves round the pole of the magnet, in a direction dependent on the pole used, and the manner in which the connections are made

piece of glass tube, the bottom part of which is closed by a cork, through which a small piece of soft iron wire passes, so as to project above and below the cork A little mercury is then

to the iron wire or the glass When a very mi nute volta c comb nat n

d wh d do d th e

e i er the connection or the pole of the magnet in contact with the iron the direction of the motion itself is changed

The small apparatus in the plate is not drawn to any scale It has been made so small as to produce rapid revolutions by the action of two plates of zinc and copper, containing not more than a square inch of surface each

In place of the ball and socket joint (Pl XVIII *Figs 3* and *4*) loops may be used or the fixed wire may terminate in a small cup con taining mercury, with its aperture upwards and the moveable wire may be bent into the form of a hook of which the extremity should be sharpened and rest in the mercury on the bottom of the cup

Note on New Electro Magnetical Motions[1]

At page 807 of this volume I mentioned the expectation I entertained of making a wire through which a current of voltaic electricity was passing obey the magnetic poles of the earth in the way it does the poles of a bar mag net In the latter case it rotates in the former I expected it would vary in weight but the attempts I then made to prove the existence of this action failed Since then I have been more successful and the object of the present note is so far to complete that paper as to show in what manner the rotative force of the wire round the terrestrial magnetic pole is exerted and what the effects produced by it are

Considering the magnetic pole as a mere centre of action the existence and position of which may be determined by well known means

with the opposite pole in the same bar for sometimes the axis was horizontal at other times vertical whilst the rotation continued the same It was also shown that the wire when influenced by the pole moved laterally its parts describing circles in planes perpendicular nearly to the wire itself Hence the wire when straight and confined to one point above de scribed a cone in its revolution but when bent

[1] *Quarterly Journal of Science* XII 416

horizon of 17° 30 measured on the magnetic

calorimotor the instrument mentioned page

an electro-magnetic wire, acted on by a magnetic pole, if the direction is otherwise than horizontal, and if they are observed in the way described in this note Thus, at the magnetic equator, for instance, where the apparent alteration of weight in an electro-magnetic wire may be expected to be greatest, the diminution of weight in its attempt to ascend would be increased by this effect, and the apparently increased gravity produced by its attempt to descend would be diminished, or perhaps entirely counteracted

I have received an account by letter from Paris, of an ingenious apparatus[1] contrived by M Ampère, to illustrate the rotatory motions described in my former paper M Ampère states that, if made of sufficient size, it will rotate by the magnetic action of the earth, and it is evident that will be the case in latitudes at some distance from the equator, if the rotary wires, namely, those by which the ring of zinc is suspended, are in such a position as to form an angle with a vertical line, larger than that formed by the direction of the dip

It is to be remarked that the motions mentioned in this note were produced by a single pair of plates, and therefore, as well as those described in the paper, page 795, are the reverse of what would be produced by two or more pair of plates It should be remembered also, that the north pole of the earth is opposite in its powers to what I have called the north poles of needles or magnets, and similar to their south poles

I may be allowed, in conclusion, to express a hope that the law I have ventured to announce, respecting the directions of the rotatory motions of an electro-magnetic wire, influenced by terrestrial magnetism, will be put to the test in different latitudes, or, what is nearly the same thing that the law laid down by M Ampère, as regulating the position taken by his curve, *namely, that it moves into a plane perpendicular to the dipping needle*, will be experimentally ascertained by all those having the opportunity

Effect of Cold on Magnetic Needles[2]

Dr De Sanctis has lately published some experiments on the effect of cold in destroying the magnetic power of needles,[3] or at least in rendering them insensible to the action of iron and other magnets Mr Ellis has claimed the merit of this discovery, and the reasoning upon it, for the late Governor Ellis Conceiving it important to establish the fact that cold as well as heat injured or destroyed the magnetic power of iron or steel, we wrapped a magnetic needle up in lint, dipped it in sulphuret of carbon, placed it on its pivot under the receiver of an air-pump, and rapidly exhausted in this way a cold, below the freezing of mercury, is readily obtained When in this state, the needle was readily affected by iron or a magnet, and the number of vibrations performed in a given time by the influence of the earth upon it were observed A fire was now placed near the pump, and the whole warmed, and when at about 80° Fahr the needle was again examined, it appeared to be just in the same state as before as to obedience to iron and a magnet, and the number of oscillations were very nearly the same, though a little greater The degree of exhaustion remained uniform throughout the experiment —Ed

Electro-magnetic Current (under the Influence of a Magnet)[4]

As the current of electricity, produced by a voltaic battery when passing through a metallic conductor, powerfully affects a magnet, tending to make its poles pass round the wire, and in this way moving considerable masses of matter, it was supposed that a reaction would be exerted upon the electric c ... (producing som ... tion being ... imation o ... , ... than magnet would diminish the current of electricity, the following experiment was made The poles of a battery of from two to thirty 4 inch plates were connected by a metallic wire formed in one part into a helix with numerous convolutions, whilst into the circuit, at another part, was introduced a delicate galvanometer The magnet was then put, in various positions, and to different extents, into the helix, and the needle of the galvanometer noticed, no effect, however, upon it could be observed The circuit was made very long, short, of wires of different metals and different diameters down to extreme fineness, but the results were always the same Magnets more and less powerful were used, some so strong as to bend the wire in its endeavours to pass round it Hence it appears that however powerful the action of an electric current may be upon a magnet, the latter has no tendency, by reaction, to diminish or increase the intensity

[1] See *Quarterly Journal of Science* XII 415

[2] *Quarterly Journal of Science* XIV, 435.

[3] *Phil. Mag*, LX 199

[4] *Quarterly Journal of Science* XIX, 338.

of the former, a fact which, though of a negative kind, appears to me to be of some importance —M F [*See* note at end of Series I of *Exp Res*, 1843]

[illegible]

friction against the metal, became so strongly electrical, that it could not be collected together, but flew about the dish whenever it was moved, and over its sides into the sand bath It required some little stirring before the particles of the powder were all of them sufficiently electrical to produce this effect It was found to take place either in porcelain, glass, or metal basins and with porcelain, glass, or metal stirrers [illegible]

The effect was not due to temperature, for when cooled out of the contact of air, it equally took place when stirred, being, however, very hygrometric, the effect soon went off if the powder were exposed to air Excited in a silver capsule and then left out of contact of the air, the substance remained electrical a great length of time, proving its very bad conducting power, and in this respect surpassing, perhaps, all other bodies The effect may be produced any number of times, and after any number of desiccations of the salt

Plat [illegible]

these effects —M F

On the General Magnetic Relations and Characters of the Metals[2]

GENERAL views have long since led me to an opinion, which is probably also entertained by others, though I do not remember to have met with it, that *all* the metals are magnetic in the same manner as iron, though not at common temperatures or under ordinary circumstances[3] I do not refer to a feeble magnetism,[4] uncertain in its existence and source, but to a distinct and decided power, such as that possessed by iron and nickel and my impression has been that there was a certain temperature for each body (well known in the case of iron) beneath which it was magnetic, but above which it lost all power, and that, further, there was some relation between this *point* of temperature and [illegible]

bodies as to liquefaction

I took occasion during the very cold weather [illegible]

low zero

The metals tried were,

Antimony	Lead
Arsenic	Mercury
Bismuth	Palladium
Cadmium	Platinum
Cobalt	Silver
Chromium	Tin
Copper	Zinc
Gold	

and also Plumbago but in none of these cases could I obtain the least indication of magnetism

Cobalt and chromium are said to be both magnetic metals. I cannot find that either of them is so, in its pure state, at any tempera-

[1] *Quarterly Journal of Science* XIX, 333
[2] *Lond. and Edinb Phil Mag* 1836 Vol VIII p 177

[3] It may be proper to remark that the observations made in par 255 of my *Experimental Researches* have reference only to the three classes of bodies there defined as existing at ordinary temperatures
[4] *Encyclop. Metrop.* Mixed Sciences Vol I p 761

tures[1] When the property was present in specimens supposed to be pure, I have traced it to iron or nickel

The step which we can make downwards in temperature is, however, so small as compared to the changes we can produce in the opposite direction, that negative results of the kind here stated could scarcely be allowed to have much weight in deciding the question under examination, although, unfortunately, they cut off all but two metals from actual comparison Still, as the only experimental course left open, I proceeded to compare, roughly, iron and nickel with respect to the points of temperature at which they cease to be magnetic In this respect iron is well known[2] It loses all magnetic properties at an orange heat, and is then, to a magnet, just like a piece of copper, silver, or any other unmagnetic metal It does not intercept the magnetic influence between a magnet and a piece of cold iron or a needle If moved across magnetic curves, a magneto-electric current is produced within it exactly as in other cases The point at which iron loses and gains its magnetic force appears to be very definite, for the power comes on suddenly and fully in small masses by a small diminution of temperature, and as suddenly disappears upon a small elevation, at that degree

With nickel I found as I expected, that the point at which it lost its magnetic relations was very much lower than with iron, but equally defined and distinct If heated and then cooled, it remained unmagnetic long after it had fallen below a heat visible in the dark and, in fact, almond oil can bear and communicate that temperature which can render nickel indifferent to a magnet By a few experiments with the thermometer it appeared that the demagnetizing temperature for nickel is near 630° or 640° A slight change about this point would either give or take away the full magnetic power of the metal

Thus the experiments, as far as they go, justify the opinion advanced at the commencement of this paper, that all metals have similar magnetic relations, but that there is a certain temperature for each beneath which it is magnetic in the manner of iron or nickel, and above which it cannot exhibit this property This magnetic capability, like volatility or fusibility, must depend upon some peculiar relation or condition of the particles of the body, and the striking difference between the necessary temperatures for iron and nickel appears to me to render it far more philosophical to allow that magnetic capability is a general property of all metals, a certain temperature being the essential condition for the development of this state, than to suppose that iron and nickel possess a physical property which is denied to all the other substances of the class

An opinion has been entertained with regard to iron, that the heat which takes away its magnetic property acts somehow within it and amongst its electrical currents (upon which the magnetism is considered as depending) as flame and heat of a similar intensity act upon conductors charged with ordinary electricity The difference of temperature necessary for iron and nickel is against this opinion, and the view I take of the whole is still more strongly opposed to it

The close relation of electric and magnetic phenomena led me to think it probable that the sudden change of condition with respect to the magnetism of iron and nickel at certain temperatures, might also affect, in some degree, their conducting power for electricity in its ordinary form but I could not, in such trials as I made, discover this to be the case with iron At the same time, although sufficiently exact to indicate a great change in conduction, they were not delicate enough to render evident any small change, which yet, if it occurred might be of great importance in illustrating the peculiarity of magnetic action under these circumstances, and might even elucidate its general nature

Before concluding this short paper, I may describe a few results of magnetic action, which, though not directly concerned in the argument above, are connected generally with the subject[3] Wishing to know what relation that temperature which could take from a magnet its power over soft iron had to that which could take from soft iron or steel its power relative to a magnet, I gradually raised the temperature of a magnet, and found that when scarcely at the boiling point of almond oil it lost its polarity rather suddenly, and then acted with a magnet as cold soft iron it required to be raised to a full orange heat before it lost its power as soft iron Hence the force of the steel to retain that condition of its particles which renders it a permanent magnet, gives way to

[1] Subsequent experiment led Faraday to the conclusion that cobalt shares magnetic properties with iron and nickel Ed

[2] See Barlow on the Magnetic Condition of Hot Iron *Phil Trans*, 1822 p 171 &c

[3] See on this subject Christie on Effects of Temperature &c *Phil Trans*, 1825 p 62 &c

heat at a far lower temperature than that which is necessary to prevent its particles as suming the *same state* by the inductive act on of a neighbouring magnet Hence at one tem perature its particles can of themselves retain a perm

dit on is lost

The temperature at which polarity was destroyed appeared to vary with the hardness

th

tion in the dark they lost their polarity but from that to a temperature a little higher being very dull ignition they acted as soft iron would do and then suddenly lost that power also Thus the loadstone retained its polarity longer than the steel magnet but lost its capability of becoming a magnet by induct on much sooner When magnetic polar ty was given to it by contact with a magnet it retained this power up to the same degree of temperature as that at which it held its first and natural magnetism

A very ingenious magnetizing process in wh ch electro-magnets and a high temperature are used has been proposed lately by M Aimé [1] I am not acquainted with the actual re-

connected as to give any advantage in pract ce however advantageous it may be to com mence the process above the depolarizing temperature.

Royal Institution January 27 1836

[1] *Annales de Ch m e et de Phys que* Vol LVII p 442

On the General Magnetic Relations and Characters of the Metals Additional Facts[2]

An idea that the metals would be all mag netic if made extremely cold as they are all non magnetic if above a certain temperature was put forth in March 1836 [3] and some experi ments were made in which several were cooled as low as −60 or −70° Fahr but without ac quiring magnetic powers It was afterwards noticed[4] that Berthier had sa d that bes des iron cobalt and nickel *manganese also possesses magnetic force beneath a certain degree of tem*

anxious to ascertain what the extremely low temperature procurable by its means would effect w th regard to the magnetic powers of metals and other substances espec ally with relation to manganese and cobalt and not hav ing seen any account of s milar trials I sen l the results to the *Philosophical Magazine* (if it please the Editors to insert them) as an appen dix to the two former notices

The substances were cooled by immers on in the mixture of ether and sol d carbonic ac d

of magnetic power was a double astatic needle each of the two constituent needles be ng small and powerful so that the whole system was very sens ble to any substance capable of hav ing magnetism induced in it when brought near one of the four poles Great care was required and was taken to avoid the effect of the down ward current of air formed by the cooled body very thin plates of mica being interposed in the most important cases

The following metals gave no indications of any magnetic power when thus cooled to −112° Fahr

Ant mony	Lead
Arsen c	Mercury
B smuth	Palla l um
Cadmium	Platinum
Chromium	Rhod um
Cobalt	S lver
Copper	T n
Gold	Zinc

[2] *Lond and Ed nb Phil Mag* 1839 Vol XIV, p 161
[3] *Ibid* Vol VIII p 177 or p 217
[4] *Ibid* Vol. IX p 65 or above

A piece of metallic manganese given to me by Mr Everett was very slightly magnetic and polar at *common* temperatures It was not more magnetic when cooled to the lowest degree Hence I believe the statement with regard to its acquiring such powers under such circumstances to be inaccurate Upon very careful examination a piece of iron was found in the piece of metal, and to that I think the magnetic property which it possessed must be attributed

I was very careful in ascertaining that pure *cobalt* did not become magnetic at the very low temperature produced

The native alloy of iridium and osmium, and also crystals of titanium, were found to be slightly magnetic at common temperatures I believe because of the presence of iron in them [1] Being cooled to the lowest degree they did not present any additional magnetic force, and therefore it may be concluded that *iridium, osmium*, and *titanium* may be added as non magnetic metals to the list already given

Carbon and the following metallic combinations were then experimented upon in a similar manner, but all the results were negative not one of the bodies gave the least sign of the acquirement of magnetic power by the cold applied

1 Carbon
2 Hæmatite
3 Protoxide of lead
4 antimony
5 bismuth
6 White arsenic
7 Native oxide of tin
8 manganese
9 Chloride of silver
10 lead
11 Iodide of mercury
12 Galena
13 Realgar
14 Orpiment
15 Dense native cinnabar
16 Sulphuret of silver
17 copper
18 tin
19 bismuth
20 antimony
21 Protosul iron crystallized
22 anhydrous

[1] See Dr Wollaston s paper on this subject, *Phil Trans* 1823 Part II or *Phil Mag* First Series Vol LXIII p 15 —Ed

The carbon was the dense hard kind obtained from gas retorts the substances 3, 4, 5, 6, 9, 10, 11, and some of the sulphurets had been first fused and solidified and all the bodies were taken in the most solid and dense state which they could acquire

It is perhaps superfluous to add, except in reference to effects which have been supposed by some to occur in northern latitudes, that the iron and nickel did not appear to suffer any abatement of their peculiar power when cooled to the very lowest degree

Royal Institution, February 7, 1839

On the Physical Lines of Magnetic Force

ROYAL INSTITUTION PROCEEDINGS, JUNE 11, 1852

On a former occasion certain lines about a bar magnet were described and defined (being those which are depicted to the eye by the use of iron filings sprinkled in the neighbourhood of the magnet), and were recommended as expressing accurately the nature, condition, direction and amount of the force in any given region either within or outside of the bar At that time the lines were considered in the abstract Without departing from or unsettling anything then said, the inquiry is now entered upon of the possible and probable *physical existence* of such lines Those who wish to reconsider the different points belonging to these parts of magnetic science may refer to two papers in the first part of the *Phil Trans* for 1852[2] for data concerning the *representative* lines of force and to a paper in the *Phil Mag*, *4th Series*, 1852, Vol III, p 401, for the argument respecting the *physical* lines of force

Many powers act manifestly at a distance, their physical nature is incomprehensible to us still we may learn much that is real and positive about them, and amongst other things something of the condition of the space between the body acting and that acted upon, or between the two mutually acting bodies Such powers are presented to us by the phenomena of gravity, light, electricity, magnetism, &c These when examined will be found to present remarkable differences in relation to their re-

[2] *See* page 758

sment a l ... f f

to magnetism

When two bodies, *a*, *b*, gravitate towards each other, the line in which they act is a straight line, for such is the line which either would follow if free to move The attractive force is not altered, either in *direction* or *amount*, if a third body is made to act by gravitation or otherwise upon either or both of the two first A balanced cylinder of brass gravitates to the earth with a weight exactly the same whether it is left like a pendulum freely to hang toward ...

tating force may be exerted upon *a* but that does not in the least affect the amount of power which it exerts towards *b* We have no evidence that *time* enters in any way into the exercise of this power, whatever the distance between the acting bodies, as that from the sun to the earth, or from star to star We can hardly conceive of this force in one particle by itself it is when two or more are present that we comprehend it yet in gaining this idea we perceive no difference in the character of the power in the different particles all of the same kind are *equal*, *mutual*, and *alike* In the case of gravitation no effect which sustains the idea of an independent or physical line of force is presented to us and as f ...

illuminating or warming power In this case rays (which are lines of force) pass across the intermediate space, but then we may affect these lines by different media applied to them in their course We may alter their direction either by reflection or refraction we may make them purs ... We ...

facts ... force They are

ing force are alike in their actions in every respect and so the line joining them has like relations in both directions The two bodies at the terminals of a ray are utterly unlike in action one is a source the other a destroyer of the line and the line itself has the relation of a stream flowing in one direction In these two cases of gravity and radiation, the difference between an abstract and a physical line of force is immediately manifest

Turning to the case of *static electricity* we find here attractions (and other actions) at a distance as in the former cases but when we come to compare the attraction with that of gravity, very striking distinctions are presented which immediately affect the question of a physical line of force In the first place when we examine the bodies bounding or terminating the lines of attraction, we find them as before, mutually and equally concerned in the action but they are not alike on the contrary though each is endued with a force which speaking generally is of the like nature still they are in such contrast that their actions on a third body in a state like either of them are precisely the reverse of each other—what the one attracts the other repels and the force makes itself evident as one of those manifestations of power endued with a dual and antithetical condition Now ...

present or be evolved more electric power of the one kind than of the other Another limitation is that they must be in physical relation to each other and that when a positive and a ...

of its power be taken up by a third ball *c* charged with negative electricity, then it can only act with 5 of power on ball *a*, and that ball must find or evolve 5 of positive power elsewhere this is quite unlike what occurs with gravity, a power that presents us with nothing dual in its ...

character Finally, the electric force acts in curved lines If a ball be electrified positively and insulated in the air, and a round metallic plate be placed about 12 or 15 inches off, facing it and uninsulated, the latter will be found, by the necessity mentioned above, in a negative condition but it is not negative only on the side facing the ball, but on the other or outer face also, as may be shown by a carrier applied there, or by a strip of gold or silver leaf hung against that outer face Now the power affecting this face does not pass through the uninsulated plate, for the thinnest gold leaf is able to stop the inductive action but round the edges of the face, and therefore acts in curved lines All these points indicate the existence of physical lines of electric force the absolutely essential relation of positive and negative surfaces to each other, and their dependence on each other contrasted with the known mobility of the forces, admit of no other conclusion The action also in curved lines must depend upon a physical line of force And there is a third important character of the force leading to the same result, namely its affection by media having different specific inductive capacities

When we pass to *dynamic electricity* the evidence of physical lines of force is far more patent A voltaic battery having its extremities connected by a conducting medium has what has been expressively called a *current of force* running round the circuit, but this current is an axis of power having equal and contrary forces in opposite directions It consists of lines of force which are compressed or expanded according to the transverse action of the conductor, which changes in direction with the form of the conductor, which are found in every part of the conductor, and can be taken out from any place by channels properly appointed for the purpose, and nobody doubts that they are physical lines of force

Finally as regards a *magnet*, which is the object of the present discourse A magnet presents a system of forces perfect in itself, and able, therefore, to exist by its own mutual relations It has the dual and antithetic character belonging to both static and dynamic electricity, and this is made manifest by what are called its *polarities* i e, by the opposite powers of like kind found at and towards its extremities These powers are found to be absolutely equal to each other; one cannot be changed in any degree as to amount without an equal change of the other, and this is true when the opposite polarities of a magnet are not related to each other, but to the polarities of other magnets. The polarities, or the *northness* and *southness* of a magnet are not only related to each other, through or within the magnet itself, but they are also related externally to opposite polarities (in the manner of static electric induction) or they cannot exist and this external relation involves and necessitates an exactly equal amount of the new opposite polarities to which those of the magnet are related So that if the force of a magnet *a* is related to that of another magnet *b*, it cannot act on a third magnet *c* without being taken off from *b*, to an amount proportional to its action on *c* The lines of magnetic force are shown by the moving wire to exist both within and outside of the magnet also they are shown to be closed curves passing in one part of their course through the magnet, and the amount of those within the magnet at its equator is exactly equal in force to the amount in any section including the whole of those on the outside The lines of force outside a magnet can be affected in their direction by the use of various media placed in their course A magnet can in no way be procured having only one magnetism or even the smallest excess of northness or southness one over the other When the polarities of a magnet are not related externally to the forces of other magnets, then they are related to each other i e, the northness and southness of an isolated magnet are externally dependent on and sustained by each other

Now all these facts, and many more, point to the existence of physical lines of force external to the magnets as well as within They exist in curved as well as in straight lines for if we conceive of an isolated straight bar magnet, or more especially of a round disc of steel magnetized regularly, so that its magnetic axis shall be in one diameter, it is evident that the polarities must be related to each other externally by curved lines of force for no straight line can at the same time touch two points having northness and southness Curved lines of force can, as I think, only consist with physical lines of force

The phenomena exhibited by the moving wire confirm the same conclusion As the wire moves across the lines of force, a current of electricity passes or tends to pass through it, there being no such current before the wire is moved The wire when quiescent has no such current, and when it moves it need not pass into places where the magnetic force is greater or less It may travel in such a course that if a magnetic needle were carried through the same course it would be entirely unaffected magneti-

cally i e., it would be a matter of absolute indifference to the needle whether it were moving or still M — h d h —

passing through both and yet when the wire moves a current of electricity shall be generated in it The mere fact of motion cannot have pro- d d

hat this state is or upon what it depends

sion or a state of vibration or perhaps some other state analogous to the electric current to

which the magnetic forces are so intimately related Whether it of necess ty requires matter for its sustentation will depend upon what is understood by the term matter If that is to be confined to ponderable or gravitating substances then *matter is not essential to the physical* lines of magnetic force any more than to a ray of light or heat but if in the assumption of an ether we admit it to be a species of matter then the lines of force may depend upon some function of it Experimentally mere space is

matter is not essential to the existence of physical lines of magnetic force

Observations on the Magnetic Force[1]

INASMUCH as the general cons derations to be brought forward have respect to those great

tion may be considered as simple and unpolar in its relat ons magnetism is dual and polar Hence *one* gravitating particle or system can not be conceived to act by gravitation as a particle or system on *itself* whereas a magnetic particle or system because of the dual nature of its force can have such a self relation Again either polarity of the magnetic force can act either by attraction or repulsion

the cases of dual powers as electric ty and magnetism but in respect of gravitation the conclusion did not seem so sure In reference to the growing magnetic relations of the sun and

moon s orbit

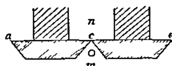
For the more careful study of the magnetic

shape but larger size formed out of glass tube

[1] *Proceedings of the Royal Institution* Jan 21 1853
[2] *Proceedings of the Royal Institution* June 11 1852 p 216 (see p 816) also *Phil Mag 4th Series* 1852 III, p 401

submitted many times in succession to the magnetic force The source of power employed was at first a large electro magnet but afterwards in order to be certain of a constant power and for the advantage of allowing any length of time for the observations the great magnet constructed by M Logeman upon the principles developed by Dr Elias (and which weighing

used in the inquiries The magnet was so arranged that the axis of power was 5 inches below the level of the glass beam the interval being traversed by the suspension filament or hook spoken of above The form and position of tl e terminations of soft iron are shown in plan by the diagram upon a scale of $\frac{1}{10}$ and also the place of the object All this part is en



and parallel to the line a e with the point of

beam they were counterpoised by a ring or rings of lead on the farther arm of the beam These when required were moved along the *beam until the latter was horizontal and that* state was ascertained by a double arm support which sustained the beam when out of

viously adjusted to its normal position and the torsion index placed at zero) it then remained to determine the return of the beam to its place when the object had been suspended on it and repelled this was done in the following manner A small plane reflector is fixed on the beam near its middle part under the point of suspension a small telescope associated with a divided scale is placed about 6 feet from the reflector and in such a position that when the beam is in its right place a given degree in the scale coincides with the fine wire in the telescope Of course the scale appears to pass by the wire as the beam itself moves and with a double angular velocity because of the reflexion As it is easy to read to the fiftieth and even

served ar t as t e rad us of tte a m o beam carrying the object was 6 inches such a quantity there would be less than $\frac{1}{2000}$th of an inch i e the return of the beam to its first or normal posit on by the torsion force put on to

amount of torsion read off on the graduated scale became the measure in degrees of the repulsive force exerted At the time of real observations the magnet balance and telescope were all fixed in a basement room upon a stone floor But it is unnecessary to describe here tl e numerous precautions requ red in relat on to

capillary action when fluids were employed as media and other circumstances or the use of

of the principles of action

When a body is submitted to the power of a

result is always differential any change in the medium changes the action on the object and there are abundance of substances which when surrounded by air are repelled and when by water are attracted upon the approach of a magnet When a certain small glass cylinder weighing only 66 grains was submitted on the

overcome the repulsive force and restore the object to its place When a vessel of water was put into the magnetic field and the experiment repeated the cylinder being now in the water was attracted and 54° 5 of torsion were required to overcome this attraction at the given distance of 0 5 If the vessel had contained a

the three bodies air glass (the especial specimen) and water have their relative force measured in relation to each other by the three experimental numbers 15°, 0° and 54° 5 If other fluids are taken as oil ether &c and employed as the med

hydrometer or of Archimedes in respect to gravity applied in the case of the magnetic forces If a different cylinder be employed of another size or substance or at a different distance the torsion numbers will be different and the zero (given by the cylinder) also different but the media (with an exception to be made hereafter) will have the same relation to each other as in the former case Therefore to bring all the experim

or this purpose every separate series of results made under exactly the same circumstances included air and water and then all the results of one series were multiplied by such

By such a process the mag between the bodies are obtained on the Centigrade scale, but the true zero is not as yet determined Either water or air or the glass may be assumed as the zero the intervals not being in any way dependent upon that point but the results will then vary in expression thus—

Air	0°	21° 6	100°
Glass	21° 6	0°	78° 4
Water	100°	78° 4	0°

all above the zero being paramagnetic and all below diamagnetic in relation to it I have adopted a vacuum as the zero in the table of results to be given hereafter

In this manner it is evident that upon principle any solid whatever its size shape or quality may be included in the list by its subjection to a magnet in air and in water or in fluids already related to these also that any fluids may be included by the use of the *same* immersed solid body for them air and water

ing always air and water in each series these

ments they are the results of calculation

as that will appear first solution of copper mentioned was colourless and the second the same solution oxidized by simple agitation in a bottle with air the copper ammonia and water being in both the same

Prot-ammo of copper	134° 23
Per-ammo of copper	119° 83
Oxygen	17° 5
Air	3° 4
Olefiant gas	0° 6
Nitrogen	0° 3
Vacuum	0° 0

(*Continued on next page*)

(Continued from preceding page)

Carbonic acid gas	0° 0
Hydrogen	0° 1
Ammonia gas	0° 5
Cyanogen	0° 9
A glass	18° 2
Pure zinc	74° 8
Ether	75° 3
Alcohol, absolute	78° 7
Oil of lemons	80°
Camphor	82° 59
Camphine	82° 96
Linseed oil	85° 56
Olive oil	85° 6
Wax	86° 73
Nitric acid	87° 96
Water	96° 6
Solution of ammonia	98° 5
Bisulphide of carbon	99° 64
Sat sol nitre	100° 08
Sulphuric acid	104° 47
Sulphur	118°
Chloride of arsenic	121° 73
Fused borate of lead	136° 6
Phosphorus	
Bismuth	1967° 6

Plücker in his very valuable paper[1] has dealt with bodies which are amongst the highly paramagnetic substances and his estimate of power is made for equal weights

One great object in the construction of an instrument delicate as that described was the investigation of certain points in the philosophy of magnetism and amongst them especially that of the right application of the law of *the inverse square of the distance as the universal* law of magnetic action Ordinary magnetic action may be divided into two kinds, that between magnets permanently magnetized and unchangeable in their condition, and *that between bodies of which one is a permanent* unchangeable magnet, and the other, having no magnetic state of its own, receives and retains its state only whilst in subjection to the first The former kind of action appears in the most rigid *and pure cases to be subject to that* law, but it would be premature to assume beforehand, and without abundant sufficient evidence, that the same law applies in the second set of cases also, for a hasty assumption might be in *opposition to the truth of nature, and therefore injurious to the progress of science,* by the creation of a preconceived conclusion We know not whether such bodies as oxygen, copper, water, bismuth, &c, owe their respective paramagnetic and diamagnetic relation to *a greater or less facility of conduction in regard* to the lines of magnetic force, *or to something* like a polarity of their particles or masses, or to some as yet unsuspected state, and there is little hope of our developing the true condition, and therefore the cause of magnetic action, *if we assume beforehand the unproved law of action* and reject the experiments that already bear upon it, for Plücker has distinctly stated as the fact, that diamagnetic force increases more rapidly than magnetic force, when the power of the dominant magnet is increased *and such a fact is contrary to the law above* enunciated The following are further results in relation to this point

When a body is submitted to the great unchanging Logeman magnet in air and in water, and the *results are reduced to the Centigrade* scale, the *relation of the three substances remains* the same for the same distance but not for *different* distances Thus, when a given cylinder of flint-glass was submitted to the magnet surrounded by air and by water, *at the distance of 0 3 of an inch, as already described* it proved to be diamagnetic in relation to both, and when the results were corrected to the Centigrade scale, and water made zero, it was 9° 1 below, *or on the diamagnetic side of water At the distance 0 4 of an inch it was 10° 6 below* water at the distance of 0 7 it was 12° 1 below water When a more diamagnetic body, as heavy glass, was employed, the same result in a higher degree was obtained for at the distance of *0 3 it was 37° 8 below water, and at that of 0 8* it was 48° 6 beneath it. Bismuth presented a still more striking case, though, as the volume of the substance was necessarily small equal *confidence cannot be placed in the exactitude of the numbers The results are given below for* the three substances, air being always 100° and water 0°, the first column of figures for each substance contains the distance[2] in tenths of an inch from the axial line of the magnetic *field and the second, the place in Centigrade magnetic* degrees below water

[1] Taylor's *Scientific Memoirs* Vol V, pp. 713 730.

[2] A given change of distance necessarily *implies* change in degree of force and change in the forms of the lines of force, but it does not imply always the same amount of change The forces are not the same at the same distance of 0 4 of an inch in opposite di*rect ons from the axial l ne towards m and n* in the figure, page 820 nor at any other equal moderate distance and though by increase and d minut on of distance the change is in the same direction it is not in the same proportion By fitly arranged *terminations* it may be made to alter with extreme rapidity in one d rection and with extreme slowness or not at all in another

Flint-Glass	Heavy Glass	Bismuth
0 3— 9° 1	0 3—37° 8	0 6—1871°
0 4—10° 6	0 4—38° 6	1 0—2734°
0 5—11° 1	0 6—40° 0	1 5—3626°
0 6—11° 2	0 8—48° 6	
0 7—12° 1	1 0—51° 5	
	1 2—65° 6	

The result here is that the greater the distance of the diamagnet ...

...pal, if an opinion may be formed from so few experiments, that the more diamagnetic the body compared to air and water, the greater does this difference become At first it was thought possible that the results might be due to some previous state induced upon the body, by its having been nearer to or farther from the magnet, but it was found that whether the progress of the experiments was from small to large distances, or the reverse, or whether, at any given d...

...were the same, no evidence of a temporary induced state could in any of these ways be found

It does not follow from the experiments, if they should be sustained by future researches, that it is the glass or the bismuth only that changes in relation to the other two bodies It may be the oxygen of the air that alters, or the water, or more probably all these bodies, for if the result be a true and natural result in these cases, it is probably common to all substances The great point is that the three bodies concerned ...

im

lat

fro

power does not, according to the experiments, remain the same, and if that result be confirmed then ...

wh

A,

the

things being the same) stand at the same point, whether at the ... of the earth, or removed

m

th

th

th

iments, stand at a different point for different distances, and if so could not be subject to the former law

The cause of this variation in the ratio of the substances one to another, if it be finally proved, has still to be searched out It may depend in some manner upon the *forms* of the lines of magnetic force, which are different at different distances, or not upon the forms of the lines, but the *amount* of power at the different distances, or not upon the mere amount, but on ...

which it is supposed that these actions are governed

...

power increases more rapidly than magnetic power with increase of force But such a circumstance, if both conclusions be accordant ...

the magnet appear to acquire a new physical state, which varies with the distance or the power of the magnet Each body may have its own rate of increase and decrease, and that may be such as to connect the extreme effect of Plucker, amongst paramagnetic bodies on ...

harmony, though it may not conform to the law of the inverse square of the distance as we now try to apply it

Plücker has already said, because of his observations regarding paramagnetic and diamagnetic force, that no correct list of magnetic substances can be given The same consequence follows, though in a different direction, from what has now been stated, and hence the reser-

vation before made (p 821) Still the former table is given as an approximation, and it may be useful for a time Before leaving this first account of recent experimental researches, it may be as well to state that they are felt to be imperfect and may perhaps even be overturned, but that, as such a result is not greatly anticipated, it was thought well to present them to the Members of the Royal Institution and the scientific world, if peradventure they might excite criticism and experimental examination, and so aid in advancing the cause of physical science

On a former occasion[1] *the existence of physical* lines of force in relation to magnetism and electricity was inferred from the dual nature of these powers, and the necessity in all cases and at all times of a relation and dependence between the polarities of the magnet, or the positive and negative electrical surfaces With respect to gravity a more hesitating opinion was expressed, because of the difficulty of observing facts having any relation to *time*, and because two gravitating particles or masses did *not seem to have any necessary dependence on* each other for the existence or excitement of their mutual power[2] A passage may now be quoted from Newton which has since been discovered in his works, and which, showing that he was an unhesitating believer in physical

trical force it is as follows, in words written to Bentley[3] ' That gravity should be innate, inherent and essential to matter, so that one body may act upon another at a distance through a *vacuum*, without the mediation of anything else by and through which their action and force may be conveyed from one to another, is

constantly according to certain laws, but whether this agent be material or immaterial, I have left to the consideration of my readers "

On Electric Induction—Associated Cases of Current and Static Effects[4]

CERTAIN phenomena that have presented themselves in the course of the extraordinary expansion which the works of the Electric Telegraph Company have undergone appeared to me to offer remarkable illustrations of some fundamental principles of electricity, and strong confirmation of the truthfulness of the view

&c) I am deeply indebted to the Company, to the gutta percha works, and to Mr Latimer Clarke for the facts, and also for the opportunity both of seeing and showing them well

Copper wire is perfectly covered with gutta percha at the Company's works, the metal and the covering being in every part regular and concentric The covered wire is usually made

ered with fine gutta percha, in such a man as to make the coating as perfect there as elsewhere the perfection of the whole operation is finally tried in the following striking manner, *by Mr Statham, the manager of the works* The half mile coils are suspended from the sides of barges floating in a canal, so that the coils are immersed in the water, whilst the two ends of each coil rise into the air as many as 200 coils are thus immersed at once, and when their ends are connected in series, one great length of 100 miles of submerged wire is produced, the two extremities of which can be brought into a

the earth, and the other, through a galvanometer, with either end of the submerged wire Passing by the first effect, and continuing the contact, it is evident that the battery current can take advantage of the whole accumulated conduction or defective insulation in the 100 miles of gutta percha on the wire, and that whatever portion of electricity passes through

electricity shown by a much coarser instrument, but when any one junction in the course of the 100 miles is separated, the current is stopped, and the leak or deficiency of insula-

[1] See p 816

tion rendered as small as before The perfection and condition of the wire may be judged of by these facts

The 100 miles, by means of which I saw the phenomena, were thus good as to insulation The copper wire was 1/16th of an inch in diameter [illegible]

wire in coils were heaped up on the floor of a dry warehouse and connected in one series, for comparison with that under water

Consider now an insulated battery of 360 pairs of plates (4×3 inches) having one extremity to the earth, the water wire with both its insulated ends in the room, and a good earth-discharge wire ready for the requisite communications when the free battery end was placed in contact with the water wire and then removed, and, afterwards, a person touching the earth-discharge touched also the wire, he received a powerful shock The shock was rather that of a voltaic than of a Leyden battery [illegible]

shocks from one charge of the wire If *time* were allowed to intervene between the charge and discharge of the wire the shock was less but it was sensible after 2, 3, or 4 minutes, or even a longer period

When, after the wire had been in contact with the battery, it was placed in contact with a Statham's fuse, it ignited the fuse (or even six fuses in succession) vividly it could ignite the fuse 3 or 4 seconds after separation from the battery [illegible]

less powerfully, after the lapse of 4 or 5 minutes, and even affected it sensibly 20 or 30 minutes after it had been separated from the battery [illegible] galvanometer was

[illegible] with the free end of the instrument, [illegible] most [illegible]

electricity rush out of the wire, holding for a

time the magnet of the instrument in the reverse direction to that due to the ingress or charge

These effects were produced equally well with [illegible]

wire

When the 100 miles of wire in the air were experimented with in like manner, not the slightest signs of any of these effects were produced There is reason, from principle to be- [illegible]

better insulated, and as regarded a constant current it was an equally good conductor This point was ascertained by attaching the end of the water wire to one galvanometer, and the end of the air wire to another like instrument, [illegible] of the wires were fastened

[illegible]

mous The surface of the copper wire is nearly 8300 square feet, and the surface of the outer coating of water is four times that amount, or 33,000 square feet Hence the striking character of the results The intensity of the static charge acquired is only equal to the intensity at the pole of the battery whence it is derived, but its quantity is enormous, because of the immense extent of the Leyden arrangement, and hence when the wire is separated from the battery and the charge employed, it has all the powers of a considerable voltaic current, and gives results which the best ordinary electric machines and Leyden arrangements cannot as yet approach

That the air wire produces none of these effects is simply because there is no outer coating correspondent to the water, or only one so far removed as to allow of no sensible induction, and therefore the inner wire cannot become charged In the air wire of the warehouse, the floor, walls, and ceiling of the place constituted the outer coating, and this was at a considerable distance, and in any case could only affect the outside portions of the coils of wire I understand that 100 miles of wire stretched

[illegible]

distance of the inductric and inducteous surfaces (1483), combined with the lower specific inductive capacity of air, as compared with gutta percha, which causes the negative result The phenomena altogether offer a beautiful case of the identity of static and dynamic electricity The whole power of a considerable battery may in this way be worked off in separate portions, and measured out in units of static force, and yet be employed afterwards for any or every purpose of voltaic electricity

I now proceed to further consequences of associated static and dynamic effects Wires cov-

[illegible]

ready described, the only difference was that as the insulation was not so perfect the charged condition fell more rapidly Consider 750 miles of the wire in one length, a galvanometer *a* being at the beginning of the wire, a second galvanometer *b* in the middle, and a third *c* at the end these three galvanometers being in the room with the experimenter, and the third *c* perfectly connected with the earth On bring-

[illegible]

time *c* when the whole 1500 miles were included, it required two seconds for the electric stream to reach the last instrument Again, all the instruments being deflected (of course not equally because of the electric leakage along the line), if the battery were cut off at *a*, that instrument instantly fell to zero, but *b* did not fall until a little while after, and *c* only after a still longer interval, a current flowing on to the end of the wire whilst there was none flowing in at the beginning Again, by a short touch of the battery pole against *a*, it could be deflected and could fall back into its neutral condition, before the electric power had reached *b*, which in its turn would be for an instant affected, and then left neutral before the power had reached *c*, a wave of force having been sent into the wire which gradually travelled along it, and made itself evident at successive intervals of time, in different parts of the wire It was even possible, by adjusted touches of the battery, to have two simultaneous waves in the wire, following each other, so that at the same moment that *c* was affected by the first wave, *a* or *b* was affected by the second, and there is no doubt that by the multiplication of instruments and close attention, four or five waves might be obtained at once

If after making and breaking battery con-

[illegible]

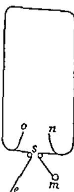
the reverse direction, so that currents will flow out of both extremities of the wire in opposite directions, whilst no current is going into it from any source Or if *a* be quickly put to the battery and then to the earth, it will show a current first entering into the wire, and then returning out of the wire at the same place, no sensible part of it ever travelling on to *b* or *c*

When an air wave of equal extent is experimented with in like manner, no such effects as

these are perce ed . f . d d 1

und the effect at galvanometer *a*, and the ac-

namely *lateral induction* and are necessary consequences of the principles of conduction, insulation, and induction, three terms which in



their meaning are inseparable from each other (*Exp Res*, 1320 1326,[1] 1338, 1561, &c) If we put a plate of shellac upon a gold leaf electrometer and a charged carrier (an insulated metal ball of two or three inches diameter) upon it the electrometer is diverged removing the carrier, this divergence instantly falls, this is *insulation* and *induction* if we replace the shellac by metal, the carrier causes the leaves to diverge as before, but when removed, though after the shortest possible contact, the electroscope is left diverged this is *conduction* If we employ a plate of spermaceti instead of the metal, and repeat the experiment, we find the divergence partly falls and partly remains because the spermaceti insulates and also conducts, doing both imperfectly, but the shellac also conducts as is shown if time be allowed and the metal also obstructs conduction and

[1] 1326 All th

therefore insulates, as is shown by simple arrangements For if a copper wire, 74 feet in

the parts near *m* and *e* brought within half an inch of each other, as at *s* then an ordinary Leyden jar being charged sufficiently, its outside connected with *e* and its inside with *m*,

portion through the air at *s* as a bright spark, for with such a length of wire the resistance in it is accumulated until it becomes as much, or perhaps even more than that of the air, for electricity of such high intensity

Admitting that such and similar experiments

explanation confirm as I think, the principles given After Mr Wheatstone had, in 1834, measured the velocity of a wave of electricity through a copper wire, and given it as 288 000 miles in a second, I said in 1838, upon the

immediately connected with two large insulated metallic surfaces exposed to the air, so that the primary act of induction after making the

surface jointly with the air and surrounding conductors then I venture to anticipate that the middle spark would be more retarded than before and if these two plates were the inner and outer coating of a large jar, or a Leyden battery, then the retardation of that spark would be still greater" Now this is precisely the case of the submerged or subterraneous wires, except that instead of carrying their sur- . . . the . coatings (1483)

tent determined externally and so the dis charge or conduction being cause l by a lower

the measured velocities of electricity in wires of metal as given by different experimenters

	Miles per second
[1] Wheatstone in 1834 with copper wire made it	288 000
[1] Walker in America with telegraph iron wire	18 780
[1] O Mitchell in America with telegraph iron wire	28 524
[1] Fizeau and Gonnelle (copper wire)	112 680
[1] Ditto (iron wire)	62 600
[2] A B G (copper) London and Brussels Telegraph	2 700
[2] A B G (copper) London and Edinburgh Telegraph	7 600

locity is not proportional to the conductive capacity and is independent of the thickness of the wire All these circumstances and incom

ascertained in a given length of wire the simple circumstances of the latter being twined round a frame in small space or spread through the air through a large space or adhering to walls or lying on the ground will make a difference in the results And in regard to long

each other

It has already been said that the conducting

current of a certain intensity is sent into a long

[1] *Liebig and Kopp's report* 1850 (translated) p 168
[2] *Athenæum*, 14th January 1854 p 54

water wire connected at the farther extremity with the earth part of the force is in the first instance occupied in raising a lateral induction round the wire ultimately equal in intensity at the near end to the intensity of the battery

be but as soon as the first has attained its maximum state then that in the wire becomes proportionate to the battery intensity and therefore equals that in the air wire in which the same state is (because of the absence of lateral induction) almost instantly attained Then of course they discharge alike and therefore conduct alike

A striking proof of the variation of the conduction of a wire by variation of its lateral static induction is given in the experiment

but if after that *n* and *o* be connected with the inside and outside of an insulated Leyden jar as described the spark will never pass across *s* but all the charge will go round the whole of the long wire Why is this? The quantity of electricity is the same the wire is the same its resistance is the same and that of the air remains unaltered but because the intensity is

of paper imbued with ferro-prussiate of potassa passes at a regular rate by clock work and thus regular lines of prussian blue are produced whenever a current is transmitted and the

time of the current is recorded In the case to be described the three lines were side by side and about 0 1 of an inch apart The pen *m* belonged to a circuit of only a few feet of wire and a separate battery it told whenever the contact key was put down by the finger the pen *n* was at the earth end of the long air wire and the pen *o* at the earth end of the long subterraneous wire and by arrangement the key could be made to throw the electricity of the chief battery into either of these wires simul

line had ceased i e after the *o* battery was cut

the record *o* showed that the wave of power took time in the water wire to reach the farther extremity by its first faintness it showed that power was consumed in the exertion of lateral static induction along the wire by the

laid up in the wire and the consequent regular falling of the induction which had been as regularly raised

With the pens *m* and *o* the conversion of an intermitting into a continuous current could be beautifully shown the earth wire by the static induction which it permitted acting in a manner analogous to the fly wheel of a steam engine or the air-spring of a pump Thus when the contact key was regularly but rapidly depressed and raised the pen *m* made a series of short lines separated by intervals of equal length After four or more of these had passed then pen *o* belonging to the subterraneous wire began to make its mark, weak at first,

ic induction

By other arrangements of the pens *n* and *o*

ner thereof were beautifully recorded but I must refrain from detailing results which have already been described in principle

Many variations of these experiments have been made and may be devised Thus the ends of the insulated battery have been attached to the ends of the long subterraneous wire and then the two halves of the wire have given back opposite return currents when connected with

and short metal wires

The character of the phenomena described

The idea of intensity or the power of overcoming resistance is as necessary to that of electricity, either static or current, as the idea of pressure is to steam in a boiler, or to air passing through apertures or tubes, and we must have language competent to express these conditions and these ideas Furthermore, I have never found either of these terms lead to any mistakes regarding electrical action, or give rise to any false view of the character of electricity or its unity I cannot find other terms of equally useful signification with these, or any which, conveying the same ideas, are not liable to such misuse as these may be subject to It would be affectation, therefore in me to search about for other words and besides that, the present subject has shown me more than ever their great value and peculiar advantage in electrical language

The fuse referred to in page 825, is of the following nature Some copper wire was covered with sulphuretted gutta percha after some months it was found that a film of sulphuret of copper was formed between the metal and the envelope and further that when half the gutta percha was cut away in any place, and then the copper wire removed by about ¼ of an inch, so as to remain connected only by the film of sulphuret adhering to the remaining gutta percha, an intensity battery could cause this sulphuret to enter into vivid ignition, and fire gunpowder with the utmost ease Gunpowder was fired with certainty at the end of eight miles of single wire, and also through 100 miles of covered wire immersed in the canal by the use of this fuse

On Some Points of Magnetic Philosophy[1]

3300 WITHIN the last three years I have been bold enough though only as an experimentalist, to put forth new views of magnetic action in papers having for titles ' On Lines of Magnetic Force '[2] and ' On Physical Lines of Magnetic Force '[3] The first paper was simply an attempt to give, for the use of experimentalists and others, a correct expression of the dual nature, amount, and direction of the magnetic power both within and outside of magnets, apart from any assumption regarding the character of the source of the power, that the mind, in reasoning forward towards new developments and discoveries, might be free from the bondage and deleterious influence of assumptions of such a nature (3075) The second paper was a speculation respecting the possible physical nature of the force, as existing outside of the magnet as well as within it, and within what are called magnetic bodies, and was expressly described as being entirely hypothetical in its character

3301 There are at present two, or rather three general hypotheses of the physical nature of magnetic action First, that of ethers carrying with it the idea of fluxes or currents, and this Euler has set forth in a simple manner to the unmathematical philosopher in his *Letters*[4] in that hypothesis the magnetic fluid or ether is supposed to move in streams through magnets, and also the space and substances around them Then there is the hypothesis of two magnetic fluids, which being present in all magnetic bodies and accumulated at the poles of a magnet, exert attractions and repulsions upon portions of both fluids at a distance, and so cause the attractions and repulsions of the distant bodies containing them Lastly, there is the hypothesis of Ampère, which assumes the existence of electrical currents round the particles of magnets, which currents, acting at a distance upon other particles having like currents, arranges them in the masses to which they belong, and so renders such masses subject to the magnetic action Each of these ideas is varied more or less by different philosophers but the three distinct expressions of them which I have just given will suffice for my present purpose My physico hypothetical notion does not go so far in assumption as the second and third of these ideas, for it does not profess to say how the magnetic force is originated or sustained in a magnet, it falls in rather with the first view yet does not assume so much Accepting the magnet as a centre of power surrounded by lines of force which, as representants of the power, are now justified by mathematical analysis (3302), it views these lines as *physical* lines of power, essential *both* to the existence of the force within the magnet, and to its conveyance to, and exertion upon, magnetic bodies at a distance Those who entertain in any degree the ether notion might consider these lines as currents, or progressive vibrations, or as stationary undulations, or as a state of tension For many reasons they should be contemplated round a wire carrying an electric current, as well as when issuing from a magnetic pole.

[1] From the *Philosophical Magazine* for February, 1855

[2] *Phil Trans* 1852 p 25

[3] *Phil Mag* 1852 June p 401

[4] *Euler's Letters* translated 1802 Vol I p. 214, Vol II pp 240 242

3302 The attention of two very able men and eminent mathematicians has fallen upon my [illegible]

on which the [illegible]

transferred into Poggendorff's *Annalen*,[4] and of which I have only a very imperfect knowledge by translated abstracts He objects, as I understand, to what I may call the physical part of my view as assigning no origin for the lines and [illegible]

[illegible] old theories, or render them superfluous, but I think I am right in believing that, as far as the lines are taken to be representations of the power [illegible]

[illegible] currents, that the mind might be delivered from the bondage of preconceived notions, but for those who desire an idea to rest upon, there is the old principle of the ethers

3303. The encouragement I derive from this appreciation by mathematicians of the mode of figuring to one's self the magnetic forces by lines, emboldens me to dwell a little more upon the further point of the true but unknown natural magnetic action Indeed, what we really want is not a variety of different methods of representing the forces, but the one true physical signification of that which is rendered apparent to us by the phenomena, and the laws governing them Of the two assumptions most usually entertained at present, magnetic fluids and electric currents, *one* must be wrong, perhaps *both* are, and I do not perceive that the mathematician, even though he may think that each contains a higher principle than any I have advanced, can tell the true from the false, or say that either is true Neither of these views could have led the mind to the phenomena of diamagnetism, and I think not to the magnetic rotation of light, and I suppose that if the question of the possibility of diamagnetic phenomena could have been asked beforehand, a mathematician, guided by either hypothesis, [illegible]

the former views, so long as they depend exclusively upon action at a distance without intermediation, and yet in the form of lines of force it represents magnetic actions truly in all that is not hypothetical. So that there are now three fundamental notions, and *two* of them at least must be impossible, i e, untrue

3304 It is evident, therefore, that our physical views are very doubtful, and I think good would result from an endeavour to shake ourselves loose from such preconceptions as are contained in them, that we may contemplate for a time the force as much as possible in its purity At present we cannot think of polarity without feeling ourselves drawn into one or the other of the two hypotheses of the origin of polar powers, and as mathematical considerations [illegible]

to the researches of modern time, but as there the use of Wheatstone's reflector, combined with Arago's suggestion of a decisive experi- [illegible]

rays, and supposing that such a view takes

[1] *Phil Mag* 1854 Vol VIII, p 53

[2] *Ibid*, p 56

[3] *Trans Royal Acad Sciences of Amsterdam*, 1854, p 17

[4] Poggendorff's *Annalen* 1853, Vol XC, p 415.

equal position with either of the two former views in representing truly the disposition of *the forces and that mathematical considerations* cannot at present decide which of the three views is either above or inferior to its corivals, it surely becomes necessary that physi [illegible]

important to obtain an answer to the inquiry [illegible]

regarding the physical hypothesis of the magnet more strongly than before (3299) to call the attention of experimenters, in a somewhat desultory manner to the subject again, both *as respects the deficiency of the present physical views* and the possible existence of lines of physical force concentrating the observations I may have to make about a few points—as *polarity duality* &c, as occasion may best [illegible]

fulness of the abstract lines of force in representing the direction and amount of the magnetic power 2 My own personal advantageous use of the lines on numerous occasions (3174), 3 The close analogy of the magnetic force and the other dual powers either in the static or dynamic state, and especially of the magnet with the voltaic battery or any other sustain- [illegible]

and final experimental settlement of the two theories of light

3306 I believe that the use by me of the [illegible]

phrase "places of force' has been considered by some as objectionable, inasmuch as it would *seem to anticipate the decision that there are* physical lines of force I will endeavour so to use it if necessary, as not to imply the assertion Nevertheless I may observe that we use such a phrase in relation to a ray of light even in those parts of the ray where it is not extinguished and where therefore we have no better knowledge of it or its existence than in similar magnetic cases, and we also use the phrase *when speaking of gravity in respect to places* where no second body to gravitate upon is present, and where when existing it cannot according to our present views cause the gravitating force of the primary body, or even the determination of it, upon that particular place

Magnetic Polarity

[illegible]

on the resultant in direction of the action of two separated and distant portions of two magnetic fluids upon other like separated portions which are either originally separate as in a magnet or are induced to separate, as in soft iron by the action of the dominant magnet it [illegible]

are no magnetic fluids but that closed currents of electricity can exist round particles of matter (or round masses), and that the known ex [illegible]

various ways by Weber, De la Rive Matteuc- [illegible]

and asserts that when an electro-conducting body moving in a constant direction near or between bodies acting magnetically on them [illegible]

interior of magnetic bodies whenever the electric current is produced and depends upon the unknown *but essential* dual or antithetical nature of the force which we call magnetism (3154)

3308 The numerous meanings of the term *polarity* and various interpretations of *polarity indications* at present current show the increasing uncertainty of the idea and the word itself Some consider that the mere set or attraction or even repulsion shown by a body

state of polarity Thomson does not view two

pole in the farther part the two ends of a bar of such matter between two dominant poles having no relation to each other [3] Becquerel

verse kind as in bismuth &c to that of the inducing magnet Others like Weber add to

phenomena (2818)

3309 The views of polar action and of mag

and developer of rea

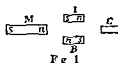


Fig 1

[1] *Athenæum* No 1406 p 1203
[2] *Ibid* column 3 at bottom
[3] *Cours spécial sur l induction* &c. p 201

latter, bringing them into like polar position with itself, and these, consistently with the simple assumption, act also upon each other as particle magnets, and exalt the polarity of the whole mass in its two extremities In like manner M should act upon B, polarizing the mass and all its particles, for the particles of the diamagnetic body B, even to the smallest, must be operated upon and we know experimentally, that a tube filled with powdered bismuth acts as a bar of the metal does But then, what is the mutual action of these bismuth particles on each other? for though all may be supposed to have a reverse polarity to that of M, they cannot in that case be reverse in respect to each other All must have like polarity, and the N of one particle must be opposed to the S of the next particle in the polarity direction That these particles act on each other must be true, and Tyndall's results on the effect of compression have proved that by the right means, namely experiment If they were supposed to have no such action on each other, it would be in contradiction to the essential nature of magnetic action, and there would remain no reason to think that the magnet itself could act on the particles, or the particles react on it If they acted on each other as the magnet is supposed to act on them, i e , to induce contrary poles, then the power of the magnet would be nullified, and the more effectually the nearer the particles were together, whereas Tyndall has shown that the bismuth magnetic condition is exalted by such vicinity of the particles, and hence we have a further right to conclude that they do act on, or influence each other, to the exaltation of the state of the mass But if the N-ness of one particle corresponds to, and aids in sustaining and exalting, the S-ness of the next particle, the whole mass must have the same kind of force, so that, as a magnet, its polarity must have the same kind of polarity as that of the particles themselves For whether a particle of bismuth be considered as acting upon a neighbouring particle or upon a distant particle of bismuth, or whether a mass of particles be considered as acting on the distant particle, the action in both cases must be precisely of the same kind

3311 But why should a polarized particle of bismuth acting upon another particle of bismuth produce in it like polarity, and with a particle of iron produce a contr... r
why should ...
tl
fe ... then the
N pole of a paramagnetic body would induce an S pole on the near end of an iron rod, whilst the N pole of a diamagnetic body would produce a pole contrary to the former, i e , an N pole at the same end of the iron rod in the same position and place This would be to assume two kinds of magnetism, i e , two north fluids (or electric currents) and two south, and the northness of bismuth would differ from the northness of iron as much as pole from pole Still more, the northness of bismuth and the southness of iron would ...
actl...

... of bis
... of iron would also prove
t... absolutely alike What is this, in fact, but to say they *are* the same? and why should we not accept the confirmation and unfailing proof that it is so, which is given to us experimentally by the moving wire? (3307, 3356)

3312 *If we employ a magnet as the originally* inducing body (3310), and entertain the idea of magnetic fluids accumulated at the poles, which act by their power of attracting each other, but repelling their like, then the inconsistency of supposing that the north fluid of a given pole can attract the north fluid of one body and the south fluid of another, or that the north and south fluids of the dominant magnet can attract one and the same fluid in bismuth and in iron, &c , is very manifest Or if we act by a solenoid or a helix of copper wire carrying an electric current instead of a magnet, and find that analogous effects are produced, are we to admit at once that the electric currents in it, acting upon the assumed electric circuits round the particles of matter, sometimes attract them on the one side and sometimes on the other? or if such bodies as bismuth and platinum are put into such a helix, are we to allow that currents in opposite directions are induced in them by one and the same inducing condition? and that, too, when all the other phenomena, and there are many, point to a uniformity of action as to direction with a variation only in power

Media

3313 Let us now consider for a time the action of different *media*, and the evidence they give in respect to polarity If a weak solution of protosulphate of iron,[1] *m*, be put into a selected thin glass tube about an inch long, and

[1] Let *l* contain 4 grains *m* 8 grains *n* 16 grains, and *o* 32 grains of crystallized protosulphate of iron in each cubic inch of water

one-third or one-fourth of an inch in diameter,

tions which have been attributed to polarity, and by which the assumed reverse polarities of paramagnetic and diamagnetic bodies have been cons...

ter are we then to conclude that it has reverse polarity in these cases? and if so, what are the reasons...

with the inversion of the phenomena for it has been shown sufficiently by former experiments,[1] that such solutions are as magnetically continuous in character as iron itself

3315 In the next place, I think it is impossible to say that the medium interposed between the magnet and the suspended cylinder of fluid can cut off, or in any way affect the direct force of the former on the latter, so as to change the direction of its internal polarity Let the tube be filled with the solution m, then if it be surrounded by the solution l it will point as iron, if the stronger solution n surround it, it will point as bismuth and with sufficient care a succession of these fluids may be arranged as indicated in *Figs 2, 3*, where the outlines between the poles represent the forms of thin glass troughs and the letters the

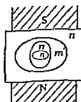


Fig 2

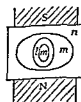


Fig 3

[1] *Phil Mag* 1846 Vol XXIX p 254

altered by the power of th...

former m m' solutions No cutting off of power

from any such interceptions would be perhaps diminutions of action, but not inversions of polarity, and every consideration indicates that all the portions of these solutions in the field at once have *like polarity* i e, like direction of force through them and like internal condition, each solution in its complex arrangement ...

like bismuth (2362 2414)

3316 These motions and pointings of the same or of different solutions, contain every ...

[2] If the polarity of the inner mass of solution is de-

it would be to make the masses of *m* and *l* and even their *form* the determining cause of the polarity, which would remove polarity altogether from dependence upon internal molecular condition, and, I think, destroy the last remains of the usual idea For my own part, I cannot conceive that when a little sphere of *m* in the solution *l* is attracted upon the approach of a given magnetic pole, and repelled under the action of the same pole when it is in the solution *n*, its particles are in the two cases polar in two opposite directions or that if for a north magnetic pole it is the *near* side of the particles of *m* when in *l* that assume the south state, it is the *farther* side which acquires the same state when the solution *l* is changed for *n* Nor can I think that when the particles of *m* have the same polar state in both solutions, the whole, as a mass, can have the opposite states

3317 These differential results run on in one uninterrupted course from the extreme of paramagnetic bodies to the extreme of diamagnetic bodies, and there is no substance within the

the one or the other condition, to be distin-

that no magnetic force exists in the space around a magnet when it is in a vacuum, it being denied that the power either crosses or reaches a locality in that space until some material substance, as the bismuth or iron, is there It is assumed that the space is in a state of magnetic

parties who make it to dismiss the consideration of differential effects when bodies are placed in a vacuum, and to divide the bodies into the well known double series of paramagnetic and diamagnetic substances But in the second place, even then, those who assume the reverse polarity of diamagnetic bodies, must assume also that the state set up in them by induction is less favourable to either the exercise or the transmission of the magnetic force than the original unpolarized state of the bismuth an assumption which is, I think, contrary to the natural action and final stable condition into which the physical forces tend to bring all bodies subject to them That a magnet acting on a piece of iron should so determine and dispose of the forces as to make the magnet and iron mutually accordant in their action, I can conceive, but that it should throw the bismuth into a state which would make it repel the magnet, whereas if unaffected it should be so far favourable as to be at least indifferent, is what I cannot imagine to myself In the third place, those who rest their ideas on *magnetic fluids*, must assume that in all diamagnetic cases, and in them only, the fundamental idea of their mutual action must not only be set aside but inverted, so that the hypothesis would be at war with itself and those who assume that *electric currents* are the cause of magnetic ef

according to that law

Time

concerned and

of force tend to bring about a stable and perma-

state of

[1] *Letters &c translated Letter LXVIII or pp.* 260–262.

the final static condition of the powers as it is afterwards Now it is very manifest, by numerous forms of experiment, that *time* enters as an element into ordinary magnetic and mag

prove the truth of the statement will be obtained In other forms of experiment and with large pieces of iron, the time which can be so

he determination of magnetic force upon it *efore* the induction than *after* whereas if ac

eems to be so brief in period as to be inappreciable by the means I have employed

3320 Professor Thomson has put this matter of time and polarity in another form If a globe of bismuth be placed without friction in the middle of the magnetic field, it will not point or move because of its shape but if it have *reverse polarity, it will be in a state of unstable equilibrium* and if *time* be an element, then the ball, being once moved on its axis ever so little would then have its polarity inclined to the magnetic axis and would go on revolving for ever, producing a perpetual motion I do not see how this consequence can be avoided, and therefore cannot admit the principles on which it rests The idea of a perpetual motion produced by static forces is philosophically illogical and impossible and so I think is the polarly opposed or adverse static condition to which I have already referred

3321 It is not necessary here that I should refer to the manner in which my view of the lines of magnetic force meet these cases for it has been done in former papers (2797, &c), but I will call the attention of those who like to

and its continuance, if, as supposed the polar state represented in the figure could be continually renewed

3322 When the north pole of a magnet re-

dition by the north end of the pole recede from it and to apply these results in the first instance to those obtained with bismuth in a vacuum before we assume a total change in principle and yet an exceptional change as to substances in the general law of magnetic polarity, without any cause assigned than, or any supporting facts beyond, the effect in question

Curved Lines of Magnetic Force—Dependence of the Dualities

3323 The representative idea of lines of magnetic force which I entertain, includes in it the thought of the curvature of these lines, not as a merely con

the lines more manageable, but as one flowing from and suggested, if not proved, by the phenomena themselves It is in this point of view that I proceed to consider it, and as the proof of the curvature is, in respect to *principle*, in the essential and necessary dependence of the two qualities or parts of a dual force upon each other (3324 &c), and in respect to *experiment*, by the numerous results supplied during the mutual actions of magnets and magnetic bodies and the phenomena of moving conductors (3337, &c), I will consider each in turn

3324 There is no known case of one form or part of a dual power existing otherwise than *with, and in dependence on, the other, which* then exists simultaneously to an equivalent, i e , an equal, degree In static electricity, where supposed electric fluids are considered as being separated from each other, they are in equal amount (1177), are ever related to each other (1681), often by curved lines of force (1215), and the existence of the one electricity without the other, or in the smallest degree of excess or deficiency, is absolutely impossible (1174) In the voltaic battery, or in the electric current produced in any other way, as by thermo arrangements or inductions, the current in one part of the circuit is absolutely the same in amount and in dual character as in another, and in the insulated, unconnected voltaic battery, where the sustaining power is internal, not the slightest development of the forces, or of either of them, can occur until circuit is completed, or induction allowed at the extremities, for if, when there is no circuit the induction be prevented, not merely no current, but no stock of electricity at the battery poles ready *to produce a current can be evolved in the* slightest degree In like manner I am fully persuaded that the northness and southness of magnetism (in whatever they may be supposed to consist) cannot exist alone, nor without exact proportion to each other, nor without mutual dependence upon each other, but that they are subject to the mutual relation and dependence of all dual force

3325 Let us consider a hard invariable magnet in space, *Fig 4* If a piece of soft iron, I, be brought towards it, the N end of the magnet will cause southness in the near end of [illegible] and northness in the [illegible] [illegible] [illegible] [illegible] [illegible] the un[illegible] ch[illegible] quality and amount (3221, 3223). *Now* to say that the force emanating from N could act on the iron, producing like and the contrary force, and then by removal of the iron, cease to act there *or elsewhere*, and then again act on the iron if approached, or anything else, and then cease to act, and so on,

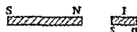


Fig 4

would in my mind be to deny the *conservation of force* and we know that there is no equivalent action within the magnet, to explain by any alternate excitement and suppression of the dual parts, any supposed appearance and disappearance of the powers at the different times for a helix closely applied round the middle part of the magnet during the experiment gives no current, and by that shows that there is no equivalent *internal* derangement of the power, when the outer exercise of it may be supposed to change between active and inert.

3326 Suppose the power of such a magnet to be due to magnetic N and S fluids, can it be thought that the N particles can be sometimes exerting their attraction for S particles, and sometimes not? Would not that be equivalent to the assumption of a suppression, i e , a destruction of force?—which surely cannot be Such an assumption could be surpassed [illegible] by that which suppose [illegible] sometim[illegible] times rep[illegible] [illegible] 3317)

3327 As to the soft iron under induction (3325), its dual magnetic forces do re-enter into their former mutually dependent and mutually satisfying state but suppose it to be replaced by steel and that *the magnetisms produced in* it do not recombine or disappear on the removal of the dominant magnet, then on what is their power ultimately turned, *if not on each other* (3257, 3324)? Where is the S power of the steel disposed of when it is separated from *its relation with the N power of the magnet* that evolved it? The case cannot be met except by affirming the independent existence of the two powers (3329), or, admitting the suppression of force, and of either of these forces the one without the other (3330), or allowing *the mutual dependence of the two polarities of* the magnet (3331)

3328 When the N pole of a magnet (*Fig 5*) is acting in free space, its force is sensible around to a certain amount (114), when a piece of soft iron, I, is brought near it, much of its force gathers up upon that iron, but the whole amount of

fneo f — — f

tron is removed from it, and falls upon the S

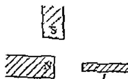


Fig 5

pole but the amount of force about the pole N remains the same, all of which can be proved

can be varied in a great variety of ways, without the slightest change in the *sum* of its amount at the source each of which gives evidence of the antithetical and inseparable condition of the two forms of force

3329 As to independent existence of the two powers (3327), how is it then that they cannot be shown separately?—not even up to the degree which is exhibited so to say, by static electricity There is nothing like a charge of northness or a charge of southness in any one of the innumerable phenomena presented by magnetism (3341) The two are just as closely connected as the two electricities of a voltaic battery whether we consider it as giving the current when

can be separated, or considered apart from each other

3330 As to the suppression of force (3327), I conceive that the creation annihilation, or suppression of force, and still more emphatically of one form only of a dual force is as impossible as the like of matter All that is permitted under the general laws of nature is to displace

whether, as it is *physically* impossible to annihilate or suppress force, it is not also *mathematically* impossible to do so, consistently with the law of the conservation of force?

3331 If we say that the forces in the cases of removal (3327) are disposed of sometimes in one direction and sometimes in another, but with the preservation of their full and equivalent amount, then how are we to consider them disposed of in the case of a cylinder or globular magnet, placed in air or *vacuo*, so as to be entirely self-dependent?—or in the case of a magnetic sphere placed in an inverted position in the magnetic field so as to be entirely surrounded and enclosed by magnetic forces having a contrary direction to its own (3238 3321)?

3332 If we say that the dualities of such a

distant mutual action either of magnetic fluids or electric currents, acting in right lines only Such action must then be through the

that these can act backwards upon each other through the magnet in straight lines so as to put the northness and southness of the pole in mutual dependence as they are supposed to be in relation to external poles without the currents themselves being *displaced and turned* until the whole magnet is neutralized falling back into the undeveloped state just as a piece of soft iron falls back When this return of state happens in soft iron or steel in any degree a helix round these shows the induced currents consequent on such a change and a loop (3133 3217) shows the difference when the iron or

put in relation to external poles of other magnets The body of the magnet and the forces passing through it remain unchanged whether examined by the loop (3223) or by its own motion or that of discs and wires associated with it (3116 &c) Its force ever remains the same in quantity and general direction

3334 The case of the steel ring magnet (3283) is well known and the manner in which such a magnet showing no external relation developes strong poles when it is broken The phenomena assure us I think that when broken the northness and southness then appearing cannot when the pieces are by themselves be determined upon each other backward through the

steel needles when many of them are made into a thick short bundle shows the same thing for if when alone the polar powers are not external but are determined upon each other through each individual magnet they are as free for a like disposal when the elementary magnets are associated as when they are separated and then there remains no sufficient reason to expect a dominant action over each other superior to that which each has over itself

3335 It is not to be supposed that the change of force which occurs when the magnet first acting externally is then made to act internally or through itself would be small and unnoticeable It should be as great as the whole amount of power which the magnet can show

no difficulty can occur in that respect and

there remain therefore in my mind but two suppositions either the N polar force of a magnet when taken off from external compensating S polar force is not exerted elsewhere as magnetic force at all or else it is externally thrown upon and associated with the S polar force of the same magnet and so sustained and disposed of for the time in its natural equivalent and essential state If converted into any new form of power what is that form? where is it disposed of? by what effects is it recognized? what are the proofs of its existence? To these inquiries there are no answers But if it be directed externally upon the opposite S pole of the magnet then all the consequences and foundations of my hypotheses of *magnetic force* and its polarity come forth and as I incline to

plied

3336 For if the dual forces of the poles of a magnet in free space are related to and dependent upon each other and yet not through the magnet (3331) then it must be through the space around Then space must have a real magnetic relation to the force passing across it

fitted to transfer the power onwards in consistency with its inevitable dual relation and in

moving conductors are presented in a simple mutual relation without any contradiction of fact or hypothesis and in perfect harmony with each other

3337 I wish to avoid prolonging *this paper* by a repetition of the considerations and reasons already advanced on former occasions and therefore will very briefly call to mind the idea I have put forth that there are such lines

of force in the space around a magnet, that the mutual dependence of the dualities, which is essential in the isolated magnet, is thus sustained, and that bodies in this space produce

called, have a magnetic relation like that of space, is easily shown by numerous experimental results, but as they have a further relation

how far the consequent results illustrate the probable condition of space where they are not present Consider a magnetic pole N, *Fig* 6, placed in relation to an equal magnetic pole S, so that their powers are mutually related and sustained, and the space between them, *a*, *a*, *a*, occupied by a vacuum, nitrogen, or some other gas at magnetic zero (2770, &c) the force exerted by N on S, or reciprocally, is easily taken cognizance of by spirals, &c, as regards any



Fig 6

and equatorial parts, we can then cause to develop (by permission of currents) a new ef-

ered, that the two poles, N and S, if free to move, do move in the same direction as the

were a prior static dependence of the magnet and the metal upon each other We know very well that the actions in the moving cases in-

would all evolve electric currents, were it not for their bad electro-conducting powers

tions of one force

If the copper revolve ever so rapidly on its axis there will be no production of currents in it and the magnetic action of N on other magnets will be the same as if the metal were quiescent or even away If N recede from C there are then currents in C though it be not

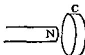


Fig 8

affected by the approximation and recession of the pole has passed from one state to another which states remain stationary as long as the poles are quiescent and it shows every character of a medium affected by the magnetic force

instead of copper the same currents in the same direction occur though in a far smaller degree and as it is believed only because of deficiency in its conducting power

3340 There can be no doubt that very much is involved in these phenomena of the nature of which we have little of no knowledge and the results obtained by Matteucci will probably lead to developments and discoveries of great importance He states that copper when finely divided presents very persisting phenomena proving its right to be considered as a diamagnetic body but that when aggregated

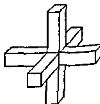
ner in which the mere difference of cohesion or division can so affect the diamagnetic character He finds too that in other respects as in Arago s rotation particles of matter act in a manner not to be anticipated from what is at present known of them as masses and it is to be hoped and expected that when these results are enlarged and developed we shall be able to form a better judgement of the true physical action of magnetism than at present

Places of No Magnetic Action

3341 The essential relation and dependence

ness or southness by concentrating either of them on one space or piece of matter and looking for their presence by effects either of tension or any other kind whether connected with polarity or not A soft iron bar an inch square 3 or 4 inches long and rounded at the edges had

be rendered magnetic by an electric current passed through the wire and a degree of adjustment in the strength of the N and S extremities could be effected by this motion of the iron in its helix Having six of these it was easy to arrange them with their like poles together so as to include a cubical space or chamber *Fig* 9 and in this space I worked by every means at my disposal Access to it was easily obtained by a previous removal of a portion of the solid angles of the ends which *were to be brought together* or by withdrawing the electro-magnets a little the one from the others and then a ray of light could be passed into or across it magnetic needles or crystals of bismuth could be suspended in it a ring helix could be introduced and rotated there and the motions of anything within could be observed by the eye outside


Fig 9

3342 A small magnetic needle hung in the

given outside t e cha ube

dle was many inches away A crystal of bismuth was entirely indifferent A piece of soft iron hung on a jointed copper wire within the chamber showed no trace of magnetic power, whether examined by the little needle or in any other manner Iron filings on a card across the chamber were not affected in the middle part but only near the partly open angles A ring helix of many convolutions, having its ter-

but with results altogether negative Attempts (though desperate) were made to ascertain if any electro-chemical conditions were induced there, but in vain Every kind of trial that I could think of, not merely by tests of a polar character, but of all sorts, were instituted, but

surely expect some condition, some tonic or static state, in a chamber thus prepared and surrounded with a high intensity of magnetic power, acting in great concentration on one particular spot or substance But it is not so, and the chamber offers a space destitute of magnetic action, and free, under the circumstances, from magnetic influence It is the complete analogue of the space presented within a deep metallic vessel or globe,[1] when charged with electricity (1174) There is then no electricity within, because that necessary connexion and dependence of the electric duals, which is essential to their nature, cannot be In like manner, there is no appearance of magnetic force in the cubical chamber, because the duals are not both there at once and one cannot be present without the other

ogy between this space and the interior of a metallic vessel charged with positive or negative electricity is A cylinder of soft iron, 9

[1] *Phil Mag* Oct 1846 Vol XXIX p 257 *note*

inches in length and 1 6 in diameter, had a chamber 0 9 in diameter and 1 inch in depth formed in one extremity concentric with the cylinder, and being placed in a powerful helix of thick copper wire, and associated with a Grove s battery of ten pair of plates, was ready for experiment a like chambered magnet can be prepared by putting a proper iron ring

magnet be placed horizontally, and a piece of cardboard be cut, so that it can enter the chamber and represent a horizontal section of its cavity and being sprinkled over with clean

those upon the surface of the card within the chamber have been left unaffected, unmoved If the chamber be filled with iron filings, closed with a card, placed in a vertical position with the aperture downward, and the magnet be then excited and the card removed, the filings will fall out as they come out they will be caught away, and form a fine fringe round the

chamber, it is strongly attracted and held there,

over the mouth

3345 If a small magnetic needle, about 0 1 of an inch long, be brought towards this excited magnet, it is almost unmanageable by reason of the force exerted upon it, but, as soon as it has entered the chamber, the power rapidly diminishes and at the bottom the needle is scarcely, if at all, affected

3346 If, instead of the core and chamber described, an iron tube of sufficient thickness of metal (as part of a gun-barrel) be employed, then like effects occur If the magnetic needle be introduced, it ceases to be acted upon when about 1 5 inch within the tube If the tube be more or less filled with iron filings, and then be excited and held vertical, they will all pour out and fall away, except those *which are retained* at the external edges Yet, if a long nail or iron rod be introduced, so as to be partly out of the cylinder, then it will be strongly attracted at the internal point, where it touches the iron of the tube core

3347 The realization of like effects by group-

four like poles are put together, *Fig 10,* they

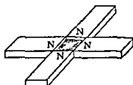


Fig 10

form a flat square chamber in the same plane

medium plane, and their greater abundance at the middle of each pole than at the re-entering

plane above, and descend from it below, and then turn back upon their course in the free space over and beneath the arrangement to-

which they are associated when the four like poles come together

3348 When the magnets are turned edges upwards, *they form a* vertical chamber 1 inch high and only 0 4 of an inch in width, and now phenomena like those just described occur, but only near the entrances to the chamber, as the little needle proceeds into the enclosed space, the power of the magnets becomes less and less, and at the middle of the chamber scarcely a trace remains, that place being, like the closed chamber, *formed with six poles* (3341), or like the bottom of a chamber formed in the end of a magnetic pole, a neutral place, or place of no magnetic action

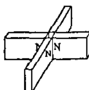


Fig 11

3349 The transition by degrees, from a pointed conical pole to an enclosed chamber, is, from the results described, very evident and so also is their connexion with those belonging to the numerous neutral places produced under ordinary circumstances (3234, *Figs 6, 10, 11, 15*) Not the slightest difficulty or hesitation occurs when these results are read or considered by the principle of representative lines of force, all the variations in the strength of the mag-

netic forces When that is diminished or inter-

from a given place, though energies of the strongest kind are directing the force on to that spot, supposing that one of the dual elements could exist in any degree without, or independent of, the other

3350 When formerly working with bismuth and magnets, I described several results (2298, 2487, 2491) *due to the principle of neutral* magnetic places, more or less developed If a sphere or cube of bismuth be delicately suspended by a vertical suspension or on a torsion balance, and an N pole be brought towards it, *Fig 12,* the bismuth will be repelled and the suspension deflected if a second N′ pole be brought up, as in the figure, the bismuth will be less repelled by N than before, will return towards it, and N′

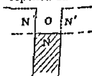


Fig 12

pole, N , be brought up on the opp the bismuth will then seem to be attracted by it, and by the first pole, and will, in fact, return

very nearly into the position it would have if all the magnets were away I thought at one time that magnetic structure given by the sec-

(3341 3347) shows also that such ought to be the case All the movements of the bismuth are the result of the tendency which it has to pass from stronger to weaker places of magnetic action (2418) and in the present case they show *that* weakened place which in a higher degree would be a place of no magnetic force

The Moving Conductor

mer papers for a statement of the principles the power and the certainty of its indications (3156 3172 3176 3270) At present I desire to apply it in a direct form of experiment to the supposed contrary polarities of iron and bismuth (3309)

3352 Four metallic spheres of copper bismuth soft iron and hard steel 0 8 of an inch

more or less rapid can be given to it by the hand

magnetic field it was so good in character as to retain very slight traces of magnetism when

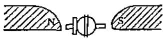




Fig 13

through places of weaker magnetic action Un-

magnetic force (3077) the results show that the polarity of the force which induces these currents and which is the magnetic force of

3354 The *bismuth* globe was placed in the

rent in either one direction or the other for as

When however, the bismuth sphere is revolved

only five or ten times, the thermo-effect is so small as to make the galvanometer deflection very little more in one direction than in the other When due attention was given, the rotation of the bismuth sphere produced an induced current in precisely the same direction as those obtained with the copper and iron and so far, therefore, it indicated precisely the same direction of polarity for the magnetic force then acting *upon* and *in* it

3355 The *hard steel* sphere, having been previously examined by a small needle and found to be unmagnetized, was placed in the magnetic field It was then revolved, and gave an induced magneto-electric current in the *same* direction as the former currents Being removed and again examined by the magnetic needle, it was found not to have received any sensible charge of magnetism

3356 So these four metal globes indicate like polarity of the magnetic force, acting upon and within them, when examined thus by the magneto-electric current due to movement across the lines of force By researches described elsewhere it is known that all metals, and all bodies which are sufficiently electro-conductors, down even to aqueous fluids, give the same direction of the magneto-electric current it is never reversed without reversion of the polarity, and reversion of the polarity *always* reverses the current induced

3357 The hard steel sphere was now *made a magnet*, and though not of good shape to retain magnetism, yet because of its hardness it was able to sustain being placed in the magnetic field, in a position the reverse of the polarity there, and yet retained its own polarity, for when taken out and examined by a magnetic needle, the polarity was found to be the same as before Such being the case, it seemed to me that this magnet might be employed to represent, according to the view of those who conceive that iron and bismuth are polarized in opposite directions in the magnetic field, both *iron* and *bismuth* inasmuch as it could be placed in the field in that condition of polarity, which these are supposed respectively to acquire there The *globe magnet* was therefore placed in the magnetic field in a position conformable to that of the dominant magnet, i e, with its N pole towards the S pole of the magnet, &c, and being rotated it gave an induced magneto-electric current like that of the standard and of iron (3352, 3353) The dominant magnet was then withdrawn to a distance (3353) and the globe rotated by itself, it gave, as it ought to do, the same current as before, for it, by its coercitive force, retains permanently that state of polarity which the iron could receive only temporarily whilst in the magnetic field being now turned 180° in a horizontal direction, the globe magnet was reversed as regarded the dominant magnet (the latter being, however, still at a distance), and now the globe magnet gave a current the *reverse* of the former, or of the standard current, and yet a very consistent current in relation to its own polarity

3358 The dominant magnet was now gradually brought up, and its effect on the reversed globe magnet observed The current from the latter became less and less, and at last was inverted, becoming like that of the standard current, nor can that be wondered at, when it is considered that the dominant magnet was the largest supplied by Logeman to the Great Exhibition, and able to sustain a weight of 430 pounds and the sphere magnet only 0 8 of an inch in diameter, and very imperfectly hardened in the interior But when the dominant magnet was withdrawn a little a place was soon found for the globe magnet, where its rotation in either direction produced no current at all Outside of this place, the rotated sphere gave a current, the reverse of that of the standard, whilst the iron and bismuth spheres in the same place, gave currents alike in kind and the *same as* that of the standard In this region, therefore (and it is like the whole of the magnetic field of many inferior yet very powerful magnets), if we represent bismuth by a magnet reversely polar, as bismuth is supposed to be, we obtain induced magneto-electric currents, not like those of bismuth, but the contrary, and if we turn the representative magnet round, so as to give it the position in which it yields currents like those of the bismuth, then its polarity contradicts, or is the reverse of the assumed polarity of the bismuth

3359 Now until the polarity or direction of the magnetic force which determines the course of the induced magneto-electric currents produced in every moving conductor, is distinguished and separated from the polarity or direction which causes movement amongst bodies subjected to the same force, how can these phenomena be accounted for by the supposition that the bismuth sphere is in the same polar condition as the reversed globe magnet? The reversed magnet is, in fact, the *contrary to* bismuth and to iron, then bismuth and iron must be the same The direct magnet is the *same* as the bismuth, in that polarity which in-

duces a current; then the magnet and the bismuth are the same How easily all these effects present themselves in a consistent form, if read by the principle of representative lines of force! The reversed globe magnet at a distance from the dominant, shows, in revolving, the effect of [illegible]

and at last the magnet is self-contained, then showing the equalization of its own powers, and as yet the absence from within it of any of the [illegible]

overpowering force of the great magnet appears (3358), which, though it can take partial possession of the little magnet, still, when removed, suffers the force of the latter to develop itself again, and present the same series of phenomena as before

3360 Van Rees admits, I believe, that the moving wire shows truly the presence, direction, and nature of the magnetic force or forces, and it is very important to know that the setting of a magnetic needle, or crystal of bismuth and the production of a current of electricity in a moving conductor, are like correlative and consequent effects of the magnetic force, the [illegible]

physical separation of the phenomena, which if established, must lead to new and important discoveries The polarity direction which the moving conductor makes manifest, whether that conductor be one of the paramagnetic or diamagnetic bodies themselves, or whether it be a conductor moving amongst them, either by itself or with them, is *always the same* The electric current produced never indicates a change in the direction of the polarity, from that belonging to the *first* source or seat of the power, whether it be a magnet, a solenoid, or [illegible]

modes of indication ever give opposite results! If opposite results seem to appear, and only [illegible]

self? especially when similar contrary phenomena in abundance are known to be produced by [illegible]

tion There is sufficient reason to admit that [illegible]

the simple and uniform results of the one mode of action, are the true indication, and that where, in the other mode, the phenomena are reversed or doubled, a part of them are *com-* [illegible]

ium in which they are observed, both point to one direction of polarity only, namely that of the dominant source of magnetism

3361 I will bring these imperfect observations to an end by a very brief statement of [illegible]

loid of power is present consisting of closed [illegible]

[illegible] to the phe- [illegible]

necting its poles varies, and so one, fully charged [illegible]

falls in power when the iron is replaced by air, or space, or bismuth Corresponding effects occur with longer or shorter magnets (3290), or with magnets made thick by adding many sideways together (3287) The medium about a magnet may be mixed in its nature and then more dual power is disposed of through the better conductor than the worse, but the whole amount of power remains unchanged The powers and utility of the media, and of space itself, fail, if the dual force or polar action be interrupted The magnet could not exist without a surrounding medium or space, and would be extinguished if deprived of it, and is extinguished, if the space be occupied adversely by the dual power of a dominant magnet of sufficient force The polarity of each line of force is in the same direction throughout the whole of its closed course Pointing in one direction or another is a differential action due to the convergence or divergence of the lines of force upon the substance acted on according as it is a better or a worse conductor of the magnetic force

3362 But though such is my view, I put it forth with all the reservation made on former occasions (3244, 3299) I do not pretend to explain all points of difficulty I have no clear idea of the physical condition constituting the charged magnetic state, i e the state of the *source of magnetic power or of the coercitivity* by which that state is either resisted in its attainment, or sustained in its permanent condition, for the hypotheses as yet put forth give no satisfaction to my mind I profess rather to point out the difficulties in the way of the views, which are at present somewhat too easily accepted, and to shake men's minds from their habitual trust in them, for, next to developing and expounding, that appears to me the most useful and effectual way of really advancing the subject —it is better to be aware, or even to suspect, we are wrong, than to be unconsciously or easily led to accept an error as right

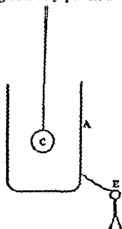
Royal Institution, Dec. 20, 1854

On Static Electrical Inductive Action[1]

To R Phillips, Esq, F R S

Dear Phillips,

Perhaps you may think the following experiments worth notice, their value consists in their power to give a very precise and decided idea to the mind respecting certain principles of inductive electrical action, which I find are by many accepted with a degree of doubt or obscurity that takes away much of their importance they are the expression and proof of *certain parts of my view of induction* Let A in the diagram represent an insulated pewter ice-pail ten and a half inches high and seven inches diameter, connected by a wire with a delicate gold-leaf electrometer E, and let C be a round brass ball insulated by a dry thread of white silk, three or four feet in length so as to remove the influence of the hand holding it from the ice-pail below Let A be perfectly discharged then let C be charged at a distance by a machine or Leyden jar, and introduced into A as in the figure If C be positive, E also will diverge positively, if C be taken away, E will collapse perfectly, the apparatus being in good order As C enters the vessel A the divergence of E will increase until C is about three inches below the edge of the vessel, and will remain *quite steady and unchanged for any greater* depression This shows that at that distance the inductive action of C is entirely exerted upon the interior of A, and not in any degree directly upon external objects If C be made to touch the bottom of A, *all* its charge is communicated to A, there is no longer any inductive action between C and A, and C, upon be-



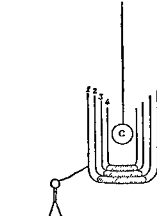
[1] *Lond. and Edinb Phil Mag*, 1843 Vol. XXII

ing withdrawn and examined is found perfectly discharged

These are all well known and recognised actions but being a little varied the following conclusions may be drawn from them If C be merely suspended in A it acts upon it by in

duces no effect upon the leaves of the electrometer it proves that the electricity *induced* by C and the electricity *in* C are accurately equal in amount and power

Again if C charged be held equidistant from the bottom and sides of A at one moment and at another be held as close to the bottom as possible without discharging to A still the divergence remains absolutely unchanged showing that whether C acts at a considerable distance or at the very smallest distance the amount of its force is the same So also if it be



held ... to the side of the ice-

the sum of their forces is the same constant

ing circumstances

I can now describe experiments with many concentric metallic vessels arranged as in the diagram where four ice-pails are represented insulated from each other by plates of shellac on which they respectively stand With this system the charged carrier C acts precisely as with the single vessel so that the intervention of many conducting plates causes no difference in the amount of inductive effect If C touch the inside of vessel 4 still the leaves are unchanged If 4 be taken out by a silk thread the leaves perfectly collapse if it be introduced again they open out to the same degree as before If 4 and 3 be connected by a wire let down

changed

Again consider the charged carrier C in the centre of the system the divergence of the electrometer measures its inductive influence this divergence remains the same whether 1 be there alone or whether all four vessels be there whether these vessels be separate as to insulation or whether 2 3 and 4 be connected so as to represent a very thick metallic vessel or whether all four vessels be connected

Again if in place of the metallic vessels 2 3

If in place of one carrier many carriers in different positions are within the inner vessel

ly over one carrier however much the distribution on each carrier may be disturbed by its neighbours If the charge of one carrier be by contact given to vessel 4 and distributed over it still the others act through and across it with the same final amount of force and no state of charge given to any of the vessels 1 2 3 or 4 prevents a charged carrier introduced within 4 acting with precisely the same amount of force as if they were uncharged If pieces of

tallic vessels

Thus a certain amount of electricity acting within the centre of the vessel A exerts exactly the same power externally whether it act by induction through the space between it and

or whether it be transferred by conduction to A, so as absolutely to destroy the previous induction within. Also, as to the inductive action, whether the space between C and A be filled with air, or with shellac or sulphur, having above twice the specific inductive capacity of air, or contain many concentric shells of conducting matter, or be nine-tenths filled with conducting matter, or be metal on one side and shellac on the other or whatever other means be taken to vary the forces, either by variation of distance or substance, or actual charge of the matter in this space, still the amount of action is precisely the same

Hence if a body be charged, whether it be a particle or a mass, there is nothing about its action which can at all consist with the idea of exaltation or extinction, the amount of force is perfectly definite and unchangeable or to those who in their minds represent the idea of the electric force by a fluid, there ought to be no notion of the compression or condensation of this fluid within itself, or of its coercibility, as some understand that phrase The only mode of affecting this force is by connecting it with force of the same kind, either in the same or the contrary direction If we oppose to it force of the contrary kind, we may *by discharge* neutralize the original force [illegible] *discharge* [illegible] princip[illegible] inducti[illegible] *[illegible] of the same kind,* there is no other state of the power in a charged body, that is, there is no state of static electric force corresponding to the terms of *simulated* or *disguised or latent* electricity away from the ordinary principles of inductive action nor is *there any case where the electricity is more latent* or *more disguised* than when it exists upon the charged conductor of an electrical machine and is ready to give a powerful spark to any body brought near it

A curious consideration arises from this perfection of inductive action Suppose a thin uncharged metallic globe two or three feet in diameter, insulated in the middle of a chamber, and then suppose the space within [illegible] occupied by [illegible] cles [illegible] ly), [illegible] the g[illegible] power would be such that t[illegible] outside of the globe would be charged with a force equal to the sum of *all* their forces and any part of this globe (not charged of itself) would give as long and powerful a spark to a body brought near it as if the electricity of all the particles near and distant were on the surface of the globe itself If we pass from this consideration to the case of a cloud, then, though we cannot altogether compare the external surface of the cloud to the metallic surface of the globe, yet the previous inductive effects upon the *earth* and its buildings are the same, and when a charged cloud is over the earth, although its electricity may be diffused over every one of its particles, and no important part of the *inductive* charge be accumulated *upon its under* surface, yet the induction upon the earth will be as strong as if all that portion of force which is directed towards the earth *were* upon that surface, and the state of the earth and its tendency to discharge to the cloud will also be as strong in the former as in the latter case As to whether lightning-discharge begins first at the cloud or at the earth, that is a matter far more difficult to decide than is usually supposed [1] theoretical notions would lead me to expect that in most cases, perhaps in all, it begins at the earth I am,

My dear Phillips, ever yours,

M FARADAY

Royal Institution February 4, 1843

[1] *Experimental Researches* Par 1370 1410 1484

A Speculation Touching Electric Conduction and the Nature of Matter[2]

TO RICHARD TAYLOR, ESQ

DEAR SIR,

Last Friday I opened the weekly evening meetings here by a subject of which the above was the title, and had no intention of publishing the matter further, but as it involves the consideration and application of a few of those main elements of natural knowledge, facts, I thought an account of its nature and intention might not be unacceptable to you, and would at the same time serve as the record of my

[2] *Lond and Edinb Phil Mag* 1844 Vol XXIV, p 136

opinion and views as far as they are at present formed

The view of the atomic constitution of matter which I think is most prevalent is that which considers the atom as a something material having a certain volume upon which those powers were impressed at the creat on which have given it from that time to the present the capab lity of constituting when many atoms are congregated together into groups the different substances whose effects and prop-

ert ... c ... T ...

... pressure or cold could not make a body contract into a smaller bulk nor heat or tension make it larger in liquids these atoms or particles are free to move about one another and in vapours or gases they are also present but removed very much farther apart though still related to each other by their powers

The atomic doctrine is greatly used one way or another in this our day for the interpretat on of phenomena especially those of crystallography and chemistry and is not so carefully distinguished from the facts but that it often appears to him who stands in the position of

word atom which can never be used without involving much that is purely hypothetical is often *intended* to be used to express a simple fact but good as the intention is I have not yet found a mind that did habitually separate it from its accompanying temptations and there can be no doubt that the words definite proportions equivalents primes &c which

stead they did not express the hypothesis as well as the fact

But it is always safe and philosophic to distinguish as much as is in our power fact from theory the experience of past ages is sufficient

ory and hypothesis from that which is the knowledge of facts and laws never raising the former to the dignity or authority of the latter nor confusing the latter more than is inevitable with the former

bodies not decomposable by the electricity to which they were subject and the relation of electricity to space contemplated as void of that which by the atomists is called matter that cons derat ons something like those which follow were presented to my mind

If the view of the constitution of matter already referred to be assumed to be correct and I may be allowed to speak of the particles of matter and of the space between them (in water or in the vapour of water for instance) as two different things then space must be taken as the only continuous part for the particles are considered as separated by space from each other Space will permeate all masses of matter in every direction like a net except that in place of meshes it will form cells isolating each atom from its neighbours and itself only being continuous

Then take the case of a piece of shellac a non-conductor and it would appear at once from such a view of its atomic const tution

every part of it cannot conduct because a non-conducting body (a res n) intervenes and separates them one from another like the supposed space in the fac

be a conductor? for it is the only continuous part of the metal, and the atoms not only do not touch (by the theory), but as we shall see presently, must be assumed to be a considerable way apart Space therefore must be a conductor, or else the metals could not conduct, but would be in the situation of the black sealing wax referred to a little while ago

But if space be a conductor, how then can shellac, sulphur, &c insulate? for space permeates them in every direction Or if space be an insulator, how can a metal or other similar body conduct?

It would seem, therefore, that in accepting the ordinary atomic theory, space may be proved to be a non-conductor in non-conducting bodies, and a conductor in conducting bodies, but the reasoning ends in this, a subversion of that theory altogether for if space be an insulator it cannot exist in conducting bodies, and if it be a conductor it cannot exist in insulating bodies. Any ground of reasoning which tends to such conclusions as these must in itself be false

In connexion with such conclusions we may consider shortly what are the probabilities that present themselves to the mind, if the extension of the atomic theory which chemists have imagined, be applied in conjunction with the conducting powers of [illegible] number of atoms in, [illegible] second column of figures the conducting power of, equal volumes of the metals named

Atoms		Conducting power
1 00	gold	6 00
1 00	silver	4 66
1 12	lead	0 52
1 30	tin	1 00
2 20	platinum	1 04
2 27	zinc	1 80
2 87	copper	6 33
2 90	iron	1 00

So here iron, which contains the greatest number of atoms in a given bulk, is the worst conductor excepting one, gold, which contains the fewest, is nearly the best conductor. Not that these conditions are in inverse proportions, for copper, which contains nearly as many atoms as iron, conducts *better still than gold,* and with *above six times the power of iron*

Lead, which contains more atoms than gold, has only about one-twelfth of its conducting power, lead, which is much heavier than tin and much lighter than platinum, has *only half the conducting power of either of these metals And all this happens amongst substances which* we are bound to consider, at present, as elementary or simple Whichever way we consider the particles of matter and the space between them, and examine the assumed constitution of matter by this table, the results are *full of perplexity*

*Now let us take the case of potassium, a compact metallic substance with excellent con*ducting powers, its oxide or hydrate a non-conductor, it will supply us with some facts having very important bearings on the assumed atomic construction of matter

When potassium is oxidized an atom of it combines with an atom *of oxygen to form an atom of potassa, and an atom of potassa com*bines with an atom of water, consisting of two atoms of oxygen and hydrogen, to form an atom of hydrate of potassa, so that an atom of hydrate of potassa contains four elementary atoms The specific gravity of potassium is 0 865, and its atomic weight 40, *the specific gravity of cast hydrate of* potassa, *in such state* of purity as I could obtain it, I found to be nearly 2, its atomic weight 57 From these, which may be taken as facts, the following strange conclusions flow A piece of potassium contains *less potassium than an equal piece of the potash formed by it and oxygen We may cast into potassium oxygen atom for atom,* and then again both oxygen and hydrogen in a twofold number of atoms, and yet, with all these additions, the matter shall become less and less, until it is not two-thirds of its original volume *If a given bulk of potassium contains 45* atoms, the *same bulk of hydrate of potassa* contains 70 atoms nearly *of the metal potassium,* and besides that, 210 atoms more of oxygen and hydrogen In dealing with [illegible] must [illegible] any k[illegible] that in [illegible] of one [illegible]

space which can contain 2800 atoms, and

very far apart in the metal, i e , there must be much more of space than of matter in that body yet it is an excellent conductor, and so space must be a conductor but then what becomes of shellac, sulphur, and all the insulators? for space must also by the theory exist in them

Again the volume which will contain 430

same number of atoms of potassium, i e , 416

only the 430 atoms of potassium as metal being entirely filled by it will after the conversion contain 256 atoms more of potassium

generally to the

pours are supposed to be more or less apart from each other, with intervening space not occupied by atoms, and perceive great contradictions in the conclusions which flow from such a view

If we must assume at all as indeed in a branch of knowledge like the present we can hardly help then the safest course appears to be to

centres of forces or powers not particles of matter in which the powers themselves reside If in the ordinary view of atoms we call the particle of matter away from the powers *a* and

trable piece of matter, and *m* is an atmosphere

Thus referring back to potassium in which as a metal the atoms must, as we have seen, be according to the usual view, very far apart from each other how can we for a moment

forces is conceived of as having no powers

powers of matter independent of a separate something to be called *the matter*, but it is certainly far more difficult, and indeed impossible,

assume the existence of that of which we are ignorant, which we cannot
wh
I
refe
twe
ly o
and ... assumption of molecules of something specially material, having powers attached in and ...

sist
fon ... is everywhere present and there ...
by it
as trul
of wat ...
stance ... in the form of ice, water or steam, no mere intervening space is present Doubtless the centres of force vary in their distance one from another, but that which is truly the matter of one atom touches the matter of its neighbours

Hence matter will be ...
ar
su
an ... space The powers ...
cent
on
m
ed
the
cor
of e

T ... conceived of as highly *elastic*, instead of being supposed excessively hard and ...

... conceived of as spherical ...
al, o
tions
decal
by ar
sides
tre of
to under the term *shape* would now be referred

to the ...
forc
cen
inte ... every direction outwards from that centre, and then a section ...

sp ... centre

In the view of matter now sustained as the lesser assumption, matter and the atoms of matter would be mutually penetrable As regards the mutual penetrability of matter, one would think that the facts respecting potassium and its compounds already described ...

side by side in a ...
chanically
represent
of power
very centre, thus forming one atom or molecule with ...

... which two or many centres of force may in this way combine, and afterwards, under the dominion of stronger forces, separate again, may in some degree be illustrated by the beautiful ...

meeting of the British Association at Liverpool It does not of course follow, from this view, that the centres shall always coincide, that will

depend upon the relative disposition of the powers of each atom

The view now stated of the constitution of matter would seem to involve necessarily the conclusion that matter fills all space, or, at least all space to which gravitation extends (including the sun and its system), for gravitation is a property of matter dependent on a certain force, and it is this force which constitutes the matter In that view matter is not merely mutually penetrable, but each atom extends so to say, throughout the whole of the

nomena of electricity, cohesion, gravitation, &c, to one force in matter, and also again with the old adage, "matter cannot act where it is not" But it is no part of my intention to enter into such considerations as these, or what the

Royal Institution January 25, 1844

On the Diamagnetic Conditions of Flame and Gases[1]

To Richard Taylor, Esq

My dear Sir,

striking evidence than that referred to in Zan-

flame is repelled from the axial line joining two

perimental confirmations and extensions of my own As M Zantedeschi has published his re-

only come in confirmation of that which has

ous in a great variety of experiments

duce others to enter actively into the new line of investigation presented by diamagnetic bodies generally

[1] *Philosophical Magazine* S 3 Vol XXXI No 210 December 1847

The effect was not instantaneous, but rose gradually to a maximum It ceased very quickly when the magnetism was removed The progressive increase is due to the gradual production of currents in the air about the magnetic field, which tend to be, and are, formed on the assumption of the magnetic conditions in the presence of the flame

When the flame was placed so as to rise truly across the magnetic axis, the effect of the magnetism was to compress the flame between the points of the poles, making it recede in the direction of the axial line from the poles towards the middle transverse plane, and also to shorten the top of the flame At the same time the top and sides of the compressed part burnt more vividly, because of two streams of air which set in from the poles on each side directly against the flame, and then passed out with it in the equatorial direction But there was at the same time a repulsion or recession of the parts of the flame from the axial line for those portions which were below did not ascend so quickly as before, and in ascending they also passed off in an inclined and equatorial direction

On raising the flame a little more, the effect of the magnetic force was to increase the intensity of the results just described, and the flame actually became of a fish tail shape, disposed across the magnetic axis

If the flame was raised until about two thirds of it were above the level of the axial line, and the poles approached so near to each other (about 0 3 of an inch) that they began to cool and compress the part of the flame at the axial line, yet without interfering with its rising freely between them, then, on rendering the magnet active, the flame became more and more compressed and shortened and as the effects proceeded to a maximum, the top at last descended, and the flame no more rose between the magnetic poles, but spread out right and left on each side of the axial line, producing a double flame with two long tongues This flame was very bright along the upper extended forked edge, being there invigorated by a current of air which *descended* from between the poles on to the flame at this part, and in fact drove it away in the equatorial direction.

When the magnet was thrown out of action, the flame resumed its ordinary upright form between the poles, at once, being depressed and redivided again by the renewal of the magnetic action.

When a small flame, only about one-third of an inch high, was placed between the poles, the magnetic force instantly flattened it into an equatorial disc

If a ball of cotton about the size of a nut be bound up by wire, soaked in ether, and inflamed, it will give a flame six or seven inches high This large flame rises freely and naturally between the poles, but as soon as the magnet is rendered active, it divides and passes off in two flames, the one on one side, and the other on the other side of the axial line

Such therefore is the general and very striking effect which may be produced on a flame by magnetic action, the important discovery of which we owe to P Bancalari

I verified the results obtained by M Zantedeschi with different flames, and found that those produced by alcohol, ether, coal gas, hydrogen, sulphur, phosphorus, and camphor were all affected in the same manner, though not apparently with equal strength The brightest flames appeared to be most affected

The chief results may be shown in a manner in some respects still more striking and instructive than those obtained with flame, by using a smoking taper A taper made of wax, coloured green by verdigris, if suffered to burn upright for a minute and then blown out, will usually leave a wick with a spark of fire on the top The subdued combustion will however still *go on* even for an hour or more, sending up a thin dense stream of smoke, which, in a quiet atmosphere, will rise vertically for six or eight inches and in a moving atmosphere will show every change of its motion both as to direction and intensity When the taper is held beneath the poles, so that the stream of smoke passes a little on one side of the axial line, the stream is scarcely affected by the power of the magnet, the taper being three or four inches below the poles, but if the taper be raised, so that the coal is not more than an inch below the axial line, the stream of smoke is much more affected, being bent outwards, and if it be brought still higher, there is a point at which the smoke leaves the taper-wick even in a horizontal direction, to go equatorially If the taper be held so that the smoke-stream passes *through* the axial line, and then the distances be varied as before, there is little or no sensible effect when the wick is four inches below but being raised, as soon as the *warm* part of the stream is between the poles, it tends to divide, and when the ignited wick is about an inch below the axial line, the smoke rises vertically in one column until about two-thirds of that distance is passed over, and then it divides, going right

and left, leaving the space between the poles clear As the taper is slowly raised, the division of the smoke descends, taking place lower down, until it occurs upon the wick, at the distance of 0 4 or 0 5 of an inch below the axial line If the taper be raised still more, the magnetic effect is so great as not only to divide the

top of the burning wick is greatly brightened by the stream of air that is impelled downwards upon it In these experiments the magnetic poles should be about 0 25 of an inch apart

A burning piece of amadou, or the end of a splinter of wood, produced the same effect

By means of a like small spark and stream of smoke, I have even rendered evident the power of an ordinary magnet The magnet was a good one and the poles were close to each other and conical in form

magnet produces similar effects upon flame and smoke, but that they are much less striking and observable

several of the flames used and a great difference exists between the matter of the flame and the surrounding air Now any or all of

the result

I placed the wires of an electrometer, and also of a galvanometer, in various parts of the affected flame, but could not procure any indications of the evolution of electricity by any action on the instruments

I examined the neighbourhood of the axial line as to the existence of any current in the air when there was no flame or heat there, using the visible fumes produced when little pellets of paper dipped in strong solutions of ammonia and muriatic acid were held near each other, and though I found that a stream of such smoke was feebly affected by the magnetic power, yet I was satisfied there was no

cles in it

But when flame or a glowing taper is used,

proceed out equatorially If the flame be driven asunder by the force of these currents and retreat, the currents follow it, and so when the flame is forked the air which is between the poles forms a current which sets from the poles downwards and sideways towards the flame I

from stronger to weaker places of magnetic force, but that hot air and flame are more so than cold or cooler air so, when flame and air, or air at different temperatures, exist at the same time within a space under the influence

nary relation to the atmosphere

It will be evident to you that I have considered flame only as a particular case of a general law It is a most important and beautiful one, and it has given us the discovery of diamagnetism in gaseous bodies but it is a comp ed one, as I shall now

alysing some of its conditions and separating their effects

For the purpose of examining the effect of heat alone in conducing to the diamagnetic condition of flame, a small helix of fine platinum wire was attached to two stronger wires of copper, so that the helix could be placed in any given position as regarded the magnetic poles, and at the same time be ignited at pleasure by a voltaic battery In this manner it was substituted for the burning taper, and gave a beautiful highly-heated current of air, unchanged in its chemical condition When the helix was placed directly under the axial line, the hot air rose up between the poles freely, being rendered evident above by a thermometer, or by burning the finger, or even scorching paper, but as soon as the magnet was rendered active, the hot air divided into a double stream, and was found ascending on the two sides of the axial line, but a descending current was formed between the poles flowing downwards towards the helix and the hot air, which rose and passed off sideways from it

It is therefore perfectly manifest that hot air is diamagnetic in relation to, or more diamagnetic than, cold air, and, from this fact I concluded, that, by cooling the air below the natural temperature, I should cause it to approach the magnetic axis or appear to be magnetic in relation to ordinary air I had a little apparatus made, in which a vertical tube delivering air was passed through a vessel containing a frigorific mixture the latter being so clothed with flannel that the external air should not be cooled, and so invade the whole of the magnetic field The central current of cold air was directed downwards a little on one side of the axial line and falling into a tube containing a delicate air-thermometer, there showed its effect On rendering the magnet active, this effect however ceased, and the thermometer rose but on bringing the latter under the axial line it again fell, showing that the cold current of air had been drawn inwards or attracted towards the axial line, i e, had been rendered magnetic in relation to air at common temperatures, or less diamagnetic than it The lower temperature was 0° F The effect was but small, still it was distinct

The effect of heat upon air, in so greatly increasing its diamagnetic condition, is very remarkable It is not, I think, at all probable that the mere effect of expanding the air is the cause of the change in its condition, because one would be led to expect that a certain bulk of expanded air would be less sensible in its diamagnetic effects than an equal bulk of denser air, just as one would anticipate that a vacuum would present no magnetic or diamagnetic effects whatever, but be at the zero point between the two classes of bodies (*Experimental Researches*, 2423, 2424) It is certainly true, that if the air were a body belonging to the magnetic class then its expansion, being equivalent to dilution, would make it seem diamagnetic in relation to ordinary air (*Experimental Researches*, 2367, 2438), but that, I think, is not likely to be the case, as will be seen by the results described further on in reference to oxygen and nitrogen

If the power conferred by heat is a direct consequence of, and proportionate to the temperature, then it gives a very remarkable character to gases and vapours, which, as we shall see hereafter, possess it in common In my former experiments (*Experimental Researches*, 2359, 2397), I heated various diamagnetic bodies, but could not perceive that their degree of magnetic force was at all increased or affected by the temperature given to them. I have again submitted small cylinders of copper and silver to the action of a single pole, at common temperatures and at a red heat, with the same result If there was any effect of increased temperature, it was that of a very slight increase in the diamagnetic force, but I am not sure of the result At present, therefore, the gaseous and vaporous bodies seem to be strikingly distinguished by the powerful effect which heat has in increasing their diamagnetic condition

As all the experiments, whether on flame, smoke, or air, seemed to show that air had a distinct magnetic relation, which, though highly affected by temperature, still belonged to it at all temperatures so it was a probable conclusion that other gaseous or vaporous bodies would be diamagnetic or magnetic, and that they would differ from each other even at common or equal temperatures I proceeded therefore to examine them, delivering streams of each into the air, in the first instance, by fit apparatus and arrangements and examining the course taken by these streams in passing across the magnetic field, the magnetic force being either induced or not at the time

In delivering the various streams, I sometimes introduced the gases into a globe with a mouth and also a tubular spout, and then poured the gas out of the spout, upwards or downwards, according as it was lighter or heavier than air. At other times, as with muriatic acid or

ammonia, I delivered the streams from the mouth of the retort But as it is very important

... to the bottom

directed into aperture *a*, and the cock of tube *c* open, twelve cubic inches of any gas within the Woulf's bottle was delivered in a minute of time, and this I found an excellent proportion for our magnet and apparatus

With respect to the delivery of this gas at the magnetic poles, a piece of glass tube bent in-

... and its vertical part be placed anywhere below the axial line The aperture at this end was

ted and disconnected in a moment, when necessary, with the tube *c* of the gas-bottle, by a short

steady and under perfect command

The next point was to detect and trace the course of these streams A little ammonia vapour, delivered near the magnetic field, did ... not satisfactory

consisting of tubes of thin glass about the size and length of a finger, open at both ends, and fixed upon little stands so that they could be adjusted either over or under the magnetic poles at pleasure When they were over the poles, I generally had three at once, one over the axial line and one at each side When they were under the poles, the lower end was turned up a little for the purpose of facilitating observation there

The gas delivered at the poles, as already described, contained a little muriatic acid (ob- ... the paper) but not

gas was perfectly clear and transparent as it ... the place of magnetic action

... were very great

netic in relation to common a

at the same temperature, but as four-fifths of the atmosphere consists of nitrogen, it seemed very evident, from the result, that nitrogen and oxygen must be very different from each other in their magnetic relations

Oxygen A stream of oxygen was sent down through air between the poles When there was no magnetic action it descended vertically, and when the magnetic action was on it appeared to do the same at all events it did not pass off equatorially But as there was reason, from the above experiments with nitrogen, to expect that oxygen would appear, not diamagnetic but magnetic in air, so the place of the stream was changed and made to be on one side of the axial line In this case it fell perfectly well at first into a catch-tube placed beneath, but as soon as the magnet was rendered active, the stream was deflected, being drawn towards the axial line, and fell into another catch tube placed there to receive it So oxygen appears to be magnetic in common air Whether it be really so, or only less diamagnetic than air (a mixture of oxygen and nitrogen), we shall be better able to consider hereafter

Hydrogen This gas proved to be clearly and even strongly diamagnetic, for notwithstanding the powerful ascensive force which its stream has in the atmosphere, because of its small specific gravity, still it was well deflected and sent equatorially Considering the lightness of the gas, one might have expected that it would have been drawn towards the axial line, as a stream of rarefied air (if it could exist) would be Its diamagnetic state therefore, shows in a striking point of view that gases, like solids, have peculiar and distinctive degrees of diamagnetic force

Carbonic acid This gas made a beautiful experiment The stream was delivered downwards a little on one side of the axial line, a catch-tube was placed a little farther out, so that the stream should fall clear of it as long as there was no activity in the magnet But on rendering the magnet efficient, the stream left its vertical direction, passed equatorially, and fell into the catch tube, and by looking horizontally, it could be seen flowing out at its lower extremity *like water, and falling away through the air* Again, the magnet was thrown out of action, and a glass with lime-water placed beneath the lower end of the catch tube, no carbonic acid appeared there, though the fluid in the glass was continually stirred, but the instant the magnet was excited the carbonic acid appeared in the catch tube, fell into the glass and made the lime-water turbid This gas therefore is diamagnetic in air

Carbonic oxide This gas was carefully freed from carbonic acid before it was used. It was employed as a descending stream, and was apparently very diamagnetic but it is to be remarked, that a substance which is so nearly of the specific gravity of atmospheric air is easily dispersed right and left in it, and therefore that the facility of dispersion is not a correct indication of the diamagnetic force By introducing a little ammonia into the mica chamber, it was, however, easily seen that carbonic oxide was driven away equatorially with considerable power, and I judge from the appearance that it is more diamagnetic than carbonic acid

Nitrous oxide This gas was moderately, but clearly, diamagnetic in air Much interest belongs to this and the other compounds of nitrogen and oxygen, both because they contain the same elements as air, and because of the relations of nitrogen and oxygen separately

Nitric oxide I tried this gas both as an up and down current, but could not determine its magnetic condition What with the action of *the oxygen of the air, the change of the nature* of the substances, and the heat produced, there was so much incidental disturbance and so little effect due to magnetic influence that I could not be sure of the result On the whole it was very slightly diamagnetic, but so little that the effect might be due to the smoke particles which served to render it visible

Nitrous acid gas Difficult to observe, but I believe it is slightly magnetic in relation to air

Olefiant gas was diamagnetic, and well so The little difference in specific gravity of this gas and air even creates a difficulty in following the course of the olefiant gas, unless it be watched for on every side

Coal-gas The coal gas of London is lighter than air, being only about two-thirds in weight of the latter It is very well diamagnetic, and gives exceedingly good and distinct results

Sulphurous acid gas is diamagnetic in air It was generated in a small tube containing liquid sulphurous acid, this being connected, in place of the gas bottle, with the delivery tube and *mouthpiece* by the vulcanized rubber tube The presence or absence of the gas in the catch-tube was well shown by ammonia, and still better by litmus paper

Muriatic acid The retort in which it was generated was connected, as just described, with the delivery tube The gas was very decidedly diamagnetic in air.

Hydriodic acid was also diamagnetic in air When there was an abundant stream of gas, its entrance into and passage through the side catch tube, on rendering the magnet active was striking When there was less gas, the stream was dispersed equatorially in all directions, and

rials in a retort, and tested in the catch tube

Chlorine was sent from the Woulf s bottle apparatus, and proved to be decidedly diamagnetic in air Either ammonia by its fumes, or litmus paper by its becoming bleached, served to indicate the entrance of the chlorine into the side catch tube every time the magnet was rendered active

Iodine A piece of glass tube was so shaped at its lower extremity as to form a chamber for the reception of iodine, which chamber had a prolonged mouth directed downwards so as to deliver the vapour formed within On putting a little iodine into the chamber, then heating it and especially the mouth part, by a spirit lamp, and afterwards inclining the apparatus, abundance of the vapour of iodine was generated as the substance flowed on to the hotter parts, and passed in a good stream from the mouth downwards This purple stream was diamagnetic in air, and could be seen flowing right and left from the axial line, when not too

air passed over it by the apparatus already described So much bromine rose into vapour as

few that are not more diamagnetic than it, and

in fact, is the cause of the comparatively low

tion where it stands for it may be as low as a vacuum, or may even pass to the magnetic side of it, and experiment does not as yet give an

the results are in favour of the idea that oxy-

really magnetic, but that a compound body possesses a specific diamagnetic force, which is not the sum of the forces of its particles

deflected than another flowing more slowly,

netic field be not filled with the gas to be examined, and that generally speaking only a moderate stream be employed, which however must depend again upon the specific gravity

The only correct way therefore of comparing two gases together is to experiment with them one in the other For the experiments made with gases, in gases or in air, are differential, and similar in their nature with those made on a former occasion with solutions (*Experimental Researches* 2362, &c) I therefore changed the surrounding medium in a few experiments, substituting other gases for air, and first selected carbonic acid as a body easy to experiment with, and one that would, probably, be more powerfully than some other of the gases, diamagnetic (I speak as to the appearances or relative results only) in air

I constructed a kind of tray or box, by folding up a doubled sheet of waxed paper thus making a vessel 13 inches long, 5 inches wide, and 5 inches high This was placed on the ends of the great magnet, and the terminal pieces of iron before described, placed in it The box was covered over loosely by plates of mica, and formed a long square chamber in which were contained the magnetic poles and field All the former arrangements in respect of the magnetic field, the delivery tube the catch tubes, &c, were then made and lastly, the box was filled with carbonic acid by a tube, which entered it at one corner and was, from time to time, supplied with a fresh portion of gas, as the previous contents became diluted with gases or air Everything answered perfectly, and the following results were easily obtained

Air passed axially, being less diamagnetic than carbonic acid gas

Oxygen passed to the magnetic axis, as was to be expected

Nitrogen went equatorially, being therefore diamagnetic, even in carbonic acid

Hydrogen, coal-gas, olefiant gas muriatic acid and *ammonia* passed equatorially in carbonic acid, and were fairly diamagnetic in relation to it

Carbonic oxide was very fairly diamagnetic in carbonic acid gas Here the effect of oxygen seems to be very well illustrated Equal volumes of carbonic oxide and carbonic acid contain equal quantities of carbon, but the former contains only half as much oxygen as the latter Yet it is more diamagnetic than the latter, so that, though an additional volume and quantity of oxygen, equal to that in the carbonic oxide, is in the carbonic acid added and compressed into it, it does not add to, but actually takes from, the diamagnetic force

Nitrous oxide appears to be slightly diamagnetic in relation to carbonic acid, but nitric oxide gas was in the contrary relation and passed towards the axial line

Hence it seems that carbonic acid, though more diamagnetic than air, is not far removed from it in that respect, and this position it probably holds because of the quantity of oxygen in it The apparent place of nitrous oxide close to it appears, in a great measure, to depend on the same circumstance of oxygen entering largely into its composition Still it is manifest that the action is not *directly* as the oxygen, for then common air would be more diamagnetic than either of them It seems rather that the forces are modified, as in the cases also of iron and oxygen, and that each compound body has its peculiar but constant intensity of action

In order to make similar experiments in light gases, the two terminal pieces of the magnet were raised, so that they might be covered by a French glass shade, which, with its stand, made a very good chamber about them The pipe to supply and change the gaseous medium and also that for bringing the gas under trial as a stream into the magnetic field, passed through holes made in the bottom of the stand. The different gases to be compared with those employed as media, were, except in the cases of ammonia and chlorine, mingled with a trace of muriatic acid, as before described The gaseous media used were two, coal gas and hydrogen Whilst using coal-gas, I observed the direction of the currents of the other gases in it by bringing a little piece of paper, at the end of a wire and dipped in ammonia solution
stream In the
a little
in the fi

Air passed towards the axial line in coal gas, but was not much affected

Oxygen had the appearance of being strongly magnetic in coal gas, passing with great impetuosity to the magnetic axis, and clinging about it, and if much muriate of ammonia fume were purposely
carried
such fo
poles I
pended
its grav
the magn ...dered active, the oxygen cloud immediately started up and took

these circumstances

Nitrogen Clearly diamagnetic in coal gas

Olefiant, *carbonic oxide*, and *carbonic acid* gasses were all slightly, but more or less diamagnetic in the coal gas

On substituting hydrogen as the surrounding medium in place of coal gas, more care was taken in the experiments Each gas experimented upon was tried in it twice at least, first in

much smoke in the stream the latter is either indifferent or tends to pass equatorially I believe that air and hydrogen cannot be far from each other

Nitrogen is strikingly diamagnetic in hydrogen

Oxygen is as strikingly magnetic in relation

centrifugal power, in relation to the axial line, was so balanced by the centripetal power produced by the magnetic action that the stream

manner

Nitric oxide This gas passed axially in hydrogen, and therefore is magnetic in relation to it

duced.

Muriatic acid gas I think it was a little dia-

other at the same temperature Foremost

cumstances

made an experiment for this purpose, but did not succeed but I am not convinced that it

their separation from a state of mixture

In the course of these experiments I subjected several of the gases to heat to ascertain whether they generally underwent the same ex-

side or the other is not as yet experimentally shown or proved

I cannot conclude this letter without expressing a hope that since gases are shown to be magnetically affected they will also shortly be

flame and heated air and gases I did not find on a former occasion (*Experimental Researches* 2397) that solid diamagnetic bodies were sensibly affected by heat but shall repeat the experiments and make more extensive ones if the Italian philosophers have not already done

heat upon iron nickel and cobalt i e heat tends in the two sets of cases either to the diminution of magnetic force or the increase of

general influence and effect upon its final motion and action subject as it is continually to the magnetic influence of the earth

I have for the sake of brevity frequently spoken in this letter of bodies as being magnetic or diamagnetic in relation one to another but I trust that in all the cases no mistake of

cially as my view of the true zero has been given only a page or two back

I am my dear Sir
Yours &c
M FARADAY

Richard Taylor Esq
Ed Phil Mag, &c, &c

INDEX

NOTE Page numbers are preceded by p or pp ; all other references are to numbered paragraphs.